A QUALITATIVE AND QUANTITATIVE STUDY OF THE SURFACE ZOOPLANKTON AT BEAUFORT, NORTH CAROLINA

BY

WILLIAM H. SUTCLIFFE

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A QUALITATIVE [illegible]

by

William H. [illegible], Jr.

Date: May 3, 1950

Approved: C. G. Bookhout
K. M. Wilbur
I. E. Gray
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H. L. Blomquist

A thesis
submitted in partial fulfillment of
the requirements for the degree
of Doctor of Philosophy in
the Graduate School of
Arts and Sciences
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Some of the plankton results of the cruises of the Penny in North Carolina are used in this paper with the permission of the North Carolina Institute of Fisheries Research, and it is through the courtesy of this organization and the U.S. Fish and Wildlife Service that the author has been able to report on the plankton of the Albatross III also from North Carolina waters.

The writer is deeply grateful for the assistance of his wife, who drew all the figures and gave much technical aid.

W. H. S., Jr.

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A QUALITATIVE AND QUANTITATIVE STUDY OF THE SURFACE ZOOPLANKTON AT BEAUFORT, NORTH CAROLINA

INTRODUCTION

General plankton investigations on the American Atlantic coast have been confined largely to the region near Woods Hole, Massachusetts. Of the older works, the two most important and comprehensive are Bigelow's detailed account of the plankton of the Gulf of Maine (1926) and a paper by Fish (1925) concerning the seasonal distribution of the plankton at Woods Hole. Bigelow's paper culminated a series of plankton reports of the area and includes discussions of a great many species of the phytoplankton and zooplankton. He is chiefly concerned with the horizontal distribution of the plankton groups in the Gulf, but includes much information as to vertical distribution and seasonal abundance. Some quantitative estimates of certain groups are given which are expressed as the number of organisms contained in a column underlying an area of water one meter square. Fish gives the seasonal distribution of a number of planktonic organisms at Woods Hole, but his graphs are based only on relative numbers. Clarke and Zinn (1937)

reported on the seasonal production of zooplankton at Woods Hole. They discussed only a few species and dealt mainly with Calanus finmarchicus (Gunner). Their results were expressed as the number of organisms per thirty minute haul, the volume of plankton after settling for one month, and the number per liter of water. Bigelow and Sears (1939) made a volumetric study of the zooplankton in the area extending from Cape Cod to Chesapeake Bay in which they studied the horizontal distribution of a number of species. Their results are expressed as "cc. per 20 minutes towing with a 1-meter net at an assumed speed of 1.2 knots." Information is included as to seasonal distribution.

Recognizing the need for a more accurate method of obtaining plankton samples and the need for standardization of results, Clarke and Bumpus (1940) devised a plankton sampler which "measured" the water passing through a net. As water passed through the net, it caused a propellor, mounted in the mouth of the net to revolve. The revolutions registered upon a cyclometer. This apparatus was calibrated for a known volume of water passing through the net per turn of the propellor. The Clarke-Bumpus sampler has been used by a number of investigators who have selected the number of organisms per cubic meter as a standard (Riley 1939; Clarke 1940; Clarke, Pierce, and Bumpus 1943; Whiteley 1948).

Recent quantitative investigations in the Woods Hole area have tended away from studies of numbers of individual groups or species and have been mainly concerned with over all rela-

tionships. Riley, Stommel, and Bumpus (1949) have just completed a comprehensive mathematical analysis of the ecological factors affecting the plankton as a whole. This analysis is based upon the results of a number of years' studies of the data of others as well as their own and is the latest of a considerable series of papers on the topic. Whiteley on the other hand, published in 1948 on the distribution of larger planktonic Crustacea of Georges Bank off Cape Cod, the site of many marine biological investigations.

Some plankton work has been done in Chesapeake Bay. Cowles (1930) made a general survey of the marine life and hydrographic conditions in the Bay in which were included observations on the plankton. He discusses the diatoms quantitatively; the zooplankton is listed as to species with notes on occurrence and relative abundance. Morse (1947) made a two year study of the plankton in the same area with particular reference to the phytoplankton and protozoa. She gives time of seasonal appearance of a considerable number of species of diatoms, dinoflagellates, and ciliates. Most of the rest of the zooplankton is grouped as Cladocera, Copepoda, Ostracoda, annelid larvae, etc. Quantitative material is given, based on percent of total plankton, with graphs of tintinids, rotifers, copepods, immature forms, dinoflagellates, and a number of species of diatoms.

Except for a few total zooplankton counts made by Riley (1938, 1939) off South Florida for comparative purposes with northern productivity and some plankton notes by Davis (1948)

in south Florida, relatively little has been done on the Atlantic coast from Chesapeake Bay southward.

It may be seen that a considerable gap exists in the knowledge of the plankton of the Atlantic coast both quantitatively and qualitatively. Except for the rather intensive work done in the New England area relatively little is known of the plankton of the more southern portions of the coast. In addition to this it was felt that an investigation of the planktonic fauna of Beaufort was needed. Although there are three marine laboratories in the area, relatively little has been done with the plankton, and it was hoped that a study of this type might help make way for further investigations of this group which is so important in the economy of the ocean. In addition to the lack of local information, the area is of particular interest because of the proximity of Beaufort to Cape Hatteras which has long been felt to be the "dividing line" between northern and essentially southern faunas. It is off Cape Hatteras that the Gulf Stream with its attendant warm waters swings away from shore.

Accordingly, the present two-year study was begun in August 1947 with the following objectives in mind: to gain some idea of the composition of the zooplankton both quantitatively and qualitatively at Beaufort, and to determine how the zooplankton is distributed with respect to time of year and certain ecological factors such as temperature, salinity, transparency, and pH.

Supplementary material from adjacent areas was examined

for comparative purposes. Collections of plankton were studied from the ocean, Pamlico Sound, and Bogue Sound. It was hoped that these would be of aid in explaining the presence of some of the plankton constituents at Beaufort.

More attention has been given the copepods in this investigation because they are numerically the most important group of zooplankton examined and because of the author's special interest in this group.

MATERIALS AND METHODS

Most of the plankton samples studied in this investigation were taken in Beaufort Channel near Shark Shoal where the water was 25 feet deep. This site was selected for reasons of accessibility, central location to nearby sounds, and proximity to the ocean. It was also hoped that the relatively strong tidal currents found there would reduce vertical stratification of organisms. Sand grains were frequently taken in the tows which were undoubtedly stirred up from the bottom.

Collections from Bogue and Pamlico Sounds as well as many of those in the ocean were made entirely by the investigators of the University of North Carolina Institute of Fisheries Research from their research vessel, the Penny, in connection with a shrimp survey of local waters. The remainder of the samples taken in the ocean are from collections[1] made from the

---

[1] Only a portion of the plankton results of the Albatross III is reported herein. The remainder will appear in a subsequent paper.

Albatross III during a recent survey of offshore Carolina waters sponsored jointly by the U.S. Fish and Wildlife Service, the Institute of Fisheries Research, and the Woods Hole Oceanographic Institution.

The laboratory work was carried out at the Duke University Marine Laboratory on Pivers Island near Beaufort and at the Department of Zoology of Duke University at Durham, North Carolina.

An attempt was made to make the Beaufort observations at two-week intervals at both high and low tides from August 1947 to August 1949. No samples were taken during the latter part of November or December, 1948, or during the early part of January 1949. Plankton tows were made with a Clarke-Bumpus sampler (Clarke and Bumpus 1940) equipped with a net size of 120 meshes to the inch (No. 10). The net was towed approximately one meter below the surface at a speed of about four knots. An average of 1100 liters were strained at each sampling.

At the time each plankton sample was taken, observations were made of water and air temperature, water transparency, hydrogen ion concentration, and general meteorological conditions. Water transparency was measured with a Secchi disc and all observations were taken after sunrise and before sunset (see discussion of this method under "Hydrographic Observations"). The pH was taken at the site of the plankton tow by means of a Lamotte "block comparator", using cresole red as an indicator. Meteorological observations included force and

direction of wind, estimate of cloud cover, and presence of absence of precipitation. Water samples were taken back to the laboratory for salinity, and later in the investigation, for oxygen determination. A set of hydrometers was used for the determination of salinity in conjunction with Knudsen's tables. Oxygen samples were first treated at the place of sampling and then in the laboratory, according to a modification of the Winkler method commonly used with salt water (Thompson and Robinson 1939). Plankton samples were preserved and diluted to 100 ml. in the laboratory with 5% formalin.

Counts of the plankton samples were made as follows: after thorough mixing and shaking of the 100 ml sample, four milliliters were withdrawn with a random sampler. This 4 ml sample was centrifuged to concentrate it and the components of the centrifugate counted in a ruled cell under a compound microscope. Counts were expressed in number of organisms per cubic meter of sea water by the use of the following formula:

$$\text{number/m}^3 \quad \frac{N \times 25 \times 1000}{R \times C}$$

where:

N number of organisms per 4 ml sample
R number of revolutions of propellor
C calibration of propellor in liters/R

After counting the aliquot sample, several portions of the remainder of the tow were examined for rare specimens which might not have been included in the 4 ml sample. Such specimens were recorded as "present". Protozoa and ctenophores cannot

counted.

As a test of the validity of the sampling method, nine successive tows were taken around a small drifting buoy (to insure the sampling of the same area of water) and four groups of organisms in the samples were counted in the prescribed manner. The results of these are given in Table I.

	Organisms No/m^3			
Tow	Paracalanus	Oithona	Nauplii	Euterpina
A	4673	2229	1597	556
B	3958	2451	1646	535
C	4333	2798	1889	576
D	4493	2437	1597	569
E	4750	2736	1743	451
F	4409	2305	1667	493
G	4715	2708	1528	493
H	4215	2576	1535	549
I	5291	2736	1653	514

Table I. Counts of consecutive plankton tows taken in approximately the same area of water.

All population graphs and tables are a result of averages of logarithms of the original number per cubic meter, unless otherwise stated. The antilogarithm of these averages (geometric means) were found and the numbers (in No/m^3) were expressed in the tables or on semilogarithmic paper for the graphs. The term "mean" is used throughout this paper to refer to these geometric means. The term "average" will denote an arithmetic mean.

Only the Beaufort material was collected on a quantitative basis. Plankton tows in Bogue Sound were made from the

pier of the Institute of Fisheries Research with a number 20 net, those in Pamlico Sound and certain others in the ocean were made from the Penny also with a number 20 net. These collections were surface tows. Samples of these tows were counted on a relative basis to estimate percent composition of the constituents. Because of the relative coarseness of the net used on the Albatross III (OXX 2XX net), this material is good only for the larger planktonic forms. Many small forms such as nauplii were not retained. All Albatross III plankton tows referred to in this study were vertical hauls from various depths rather than surface collections.

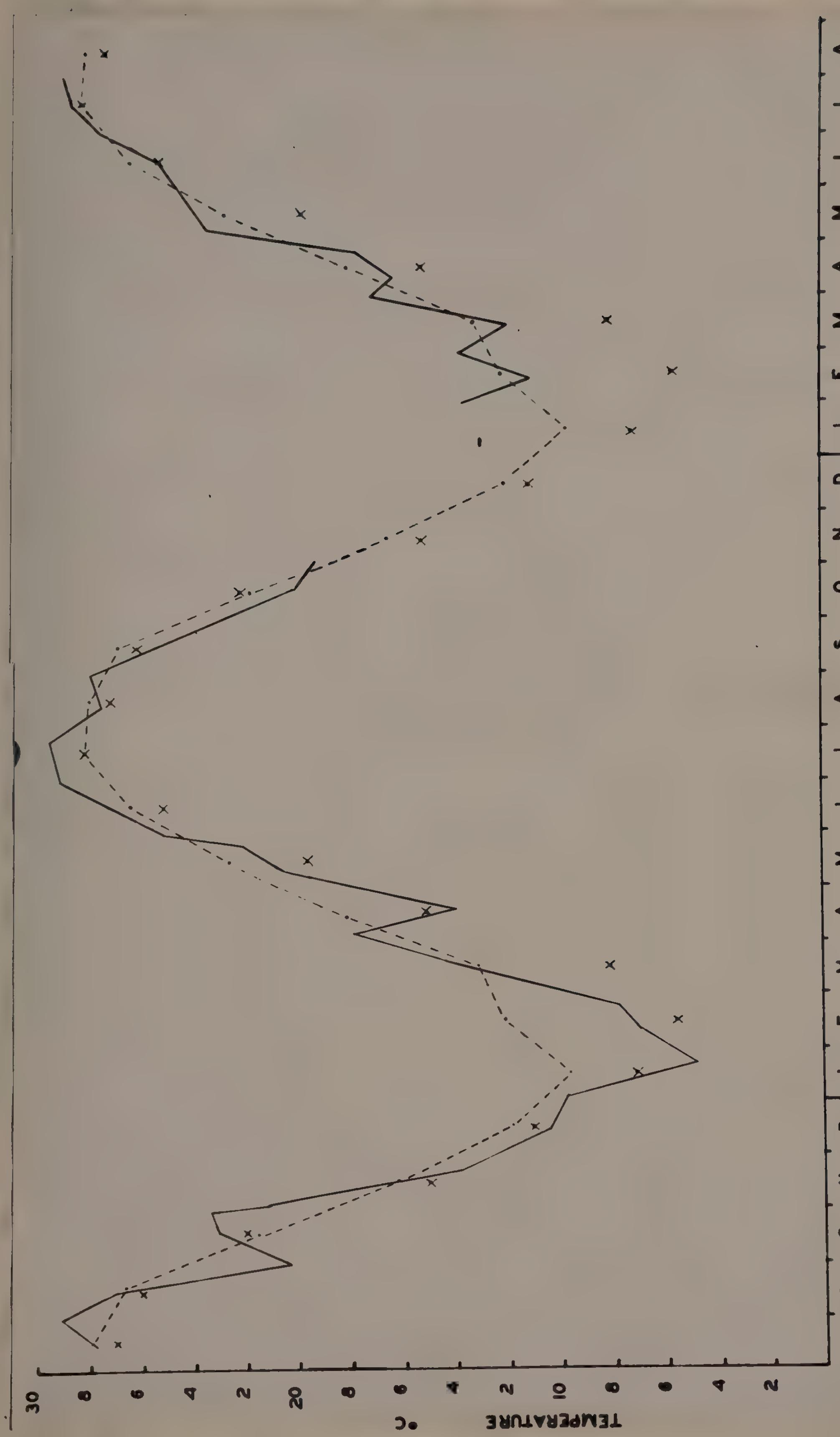
HYDROGRAPHIC OBSERVATIONS

Beaufort Inlet

Temperature

A record of temperatures (high and low tide averages) taken during the period of observations may be seen in Figure 1. Also shown for comparison are the temperatures found at Beaufort by Gutsell (1931) and McDougall (1943). Gutsell's figures represent five year means (1924-1928) of monthly maxima and minima based on one reading daily at the U.S. Fish and Wildlife Laboratory. McDougall's information is of monthly means taken from March 1941- Februgry 1942 at the Duke Marine Laboratory. Except for what was apparently an unusually cold winter in 1948, if compared with Gutsell's "average temperatures", the present findings do not appear to vary radically from what might normally be expected. The winter temperatures recorded by McDougall were nearly as cold. Gutsell has recorded temperatures as low as 3°C for January.

Figure 1. High and low tide averages of water temperatures. Gutsell (1931) ----; McDougall (1943) x x x ; present investigation ____ .


TEMPERATURE °C
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The maxima, minima, and averages (°C) for low and high tides found in the present investigation were as follows:

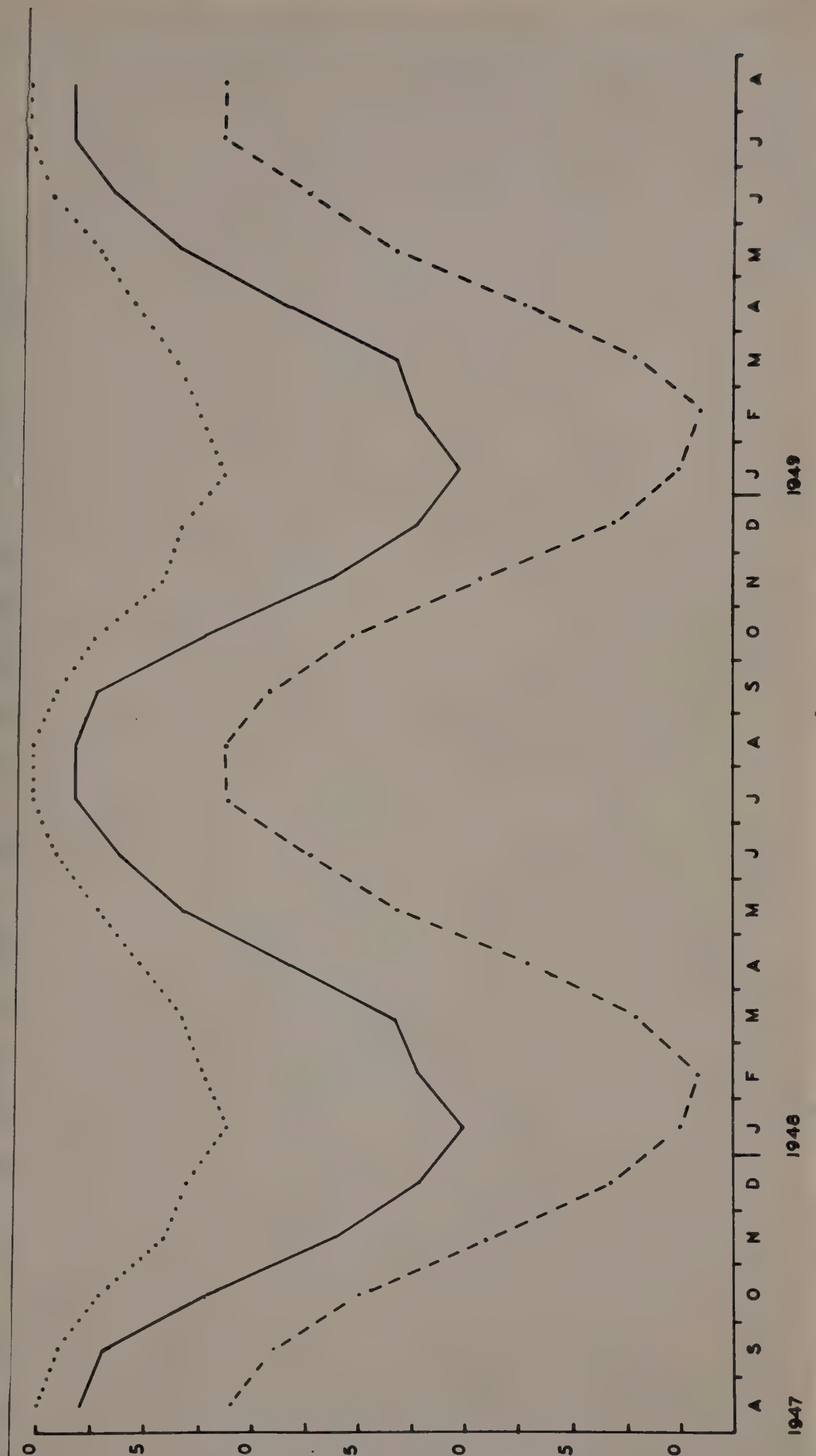
	Maximum	Minimum	Average(total)
High tide	28.8 July 24,'48	5.5 Jan.20,'48	19.6
Low tide	29.9 July 23,'48	4.5 Jan.20,'48	19.8

High and low tides as an average did not differ greatly in temperature. Low tide temperatures, however, were somewhat lower in winter and higher in summer. These differences are probably due to mixing at high tide with ocean water of more stable temperatures and to warming (or cooling) of low tide water on flats. Influxes of fresher waters as well as evaporation rates might also influence low tide temperatures.

Figure 2 shows a comparison of monthly averages of Woods Hole (after McDougall 1943 from Sumner et al. 1913), Beaufort Inlet (Gutsell 1931), and Miami Beach (U.S. Coast and Geodetic Survey 1947). It may be seen that the Beaufort record is intermediate between the other two. Its range overlaps the others and there are at certain times of the year agreements of temperature with each of the other two localities. That is, the summer temperatures at Beaufort are similar to winter temperathres at Miami Beach and winter temperatures at Beaufort are similar to summer temperatures at Woods Hole. Figure 3 shows these temperature ranges in a different form.

The terms "tropical" and "northern" will be used here in a broad sense. There is no attempt being made to establish ecological regions, for that is not the object of the present study. However, for the purposes of this paper "tropical" is used to indicate warm waters (year round temperature usually

Figure 2. Monthly averages of water temperatures of Miami Beach ..... ; Beaufort Inlet ____ ; Woods Hole -.-.- -. For sources see text.


TEMPERATURE °C
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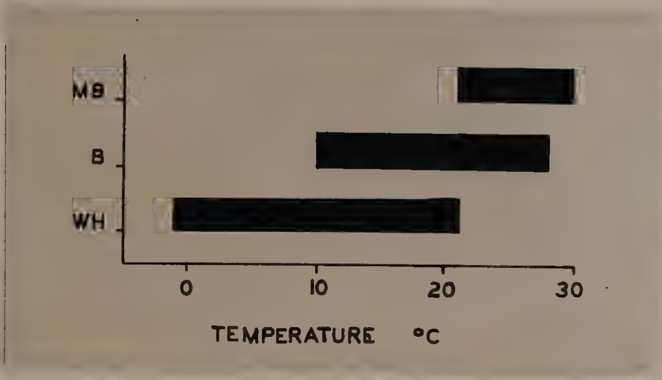


Figure 3. Average temperature ranges for Miami Beach (MB), Beaufort (B), Woods Hole (WH).

greater than 20°C) generally associated with low latitudes such as southern Florida southward. "Northern" indicates colder waters as of the Woods Hole area and northward, with temperatures usually below 20°C the year round. "Temperate" will indicate intermediates between these two.

Salinity

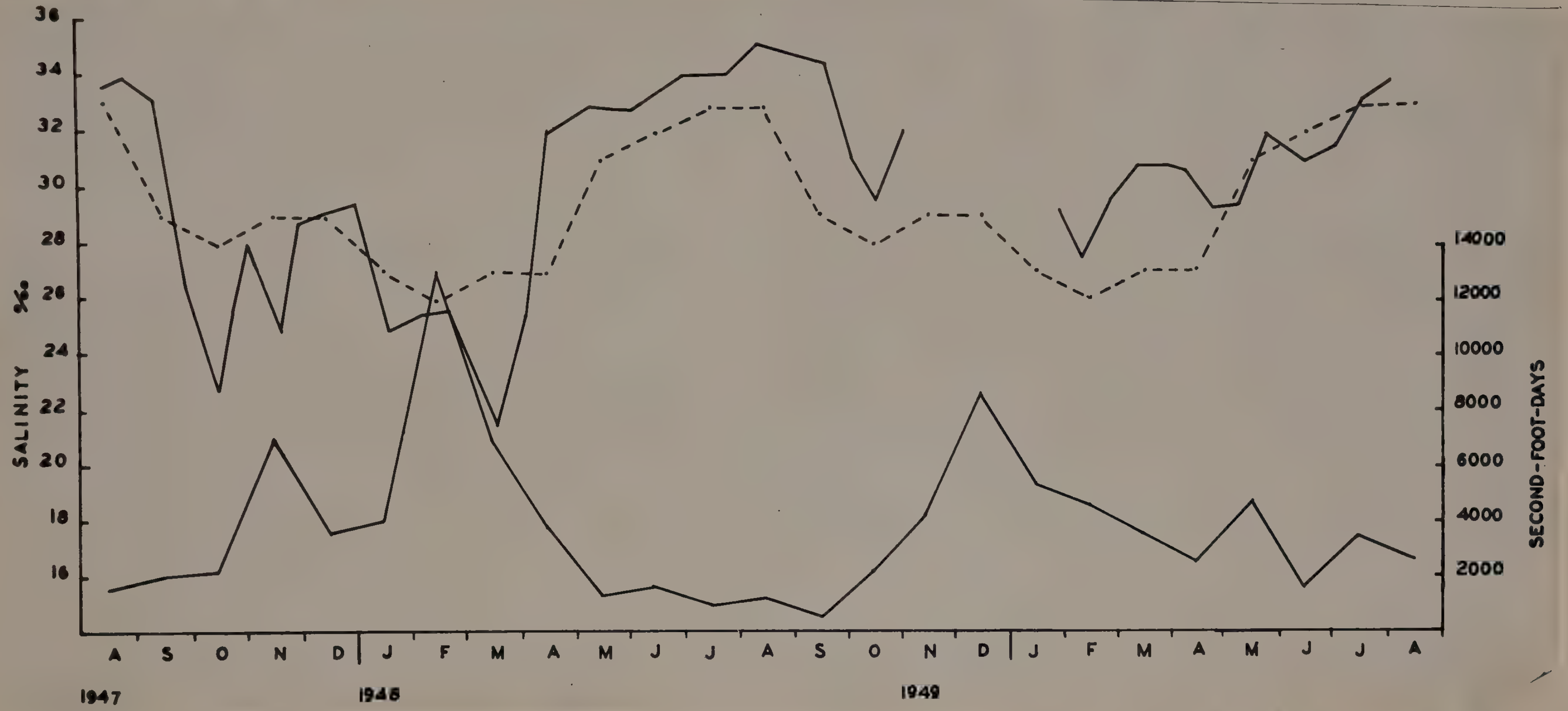
The salinities observed over the two-year period in this investigation are shown in Figure 4 together with monthly averages of those obtained by Gutsell (1931) from 1924-1928. The low salinities of winter and early spring in 1948 correspond to a series of unusually low tides. High and low tide peaks obtained at Beaufort Inlet follow (o/oo):

	Maxima	Minima	Average(total)
High tide	35.4 Aug.29,'48	25.1 Mar.18'48	31.9
Low tide	35.2 Aug.12,'48	17.7 Mar.18'48	28.7

Gutsell recorded extremes of salinity as low as 6o/oo and as high as 38o/oo.

It may be seen from Figure 4 that there were in general

Figure 4. Salinity and runoff. Gutsell (1931) -----; present investigation upper _____; runoff values for Neuse River,Kinston, N.C. lower ____ .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higher salinities in summer and lower in winter. Differential evaporation rates in winter and summer are possibly a factor in this as well as the presence of greater or lesser amounts of oceanic water from Onslow Bay (Figure 6) caused by winds. Also to be considered are the shifting of offshore circulation and the fluctuations of land runoff through Beaufort Inlet. Higher temperatures and salinities were more or less concurrent as shown in Figure 5.

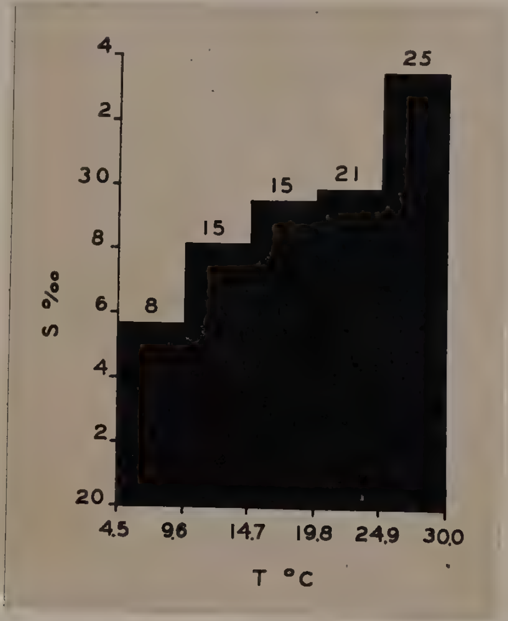
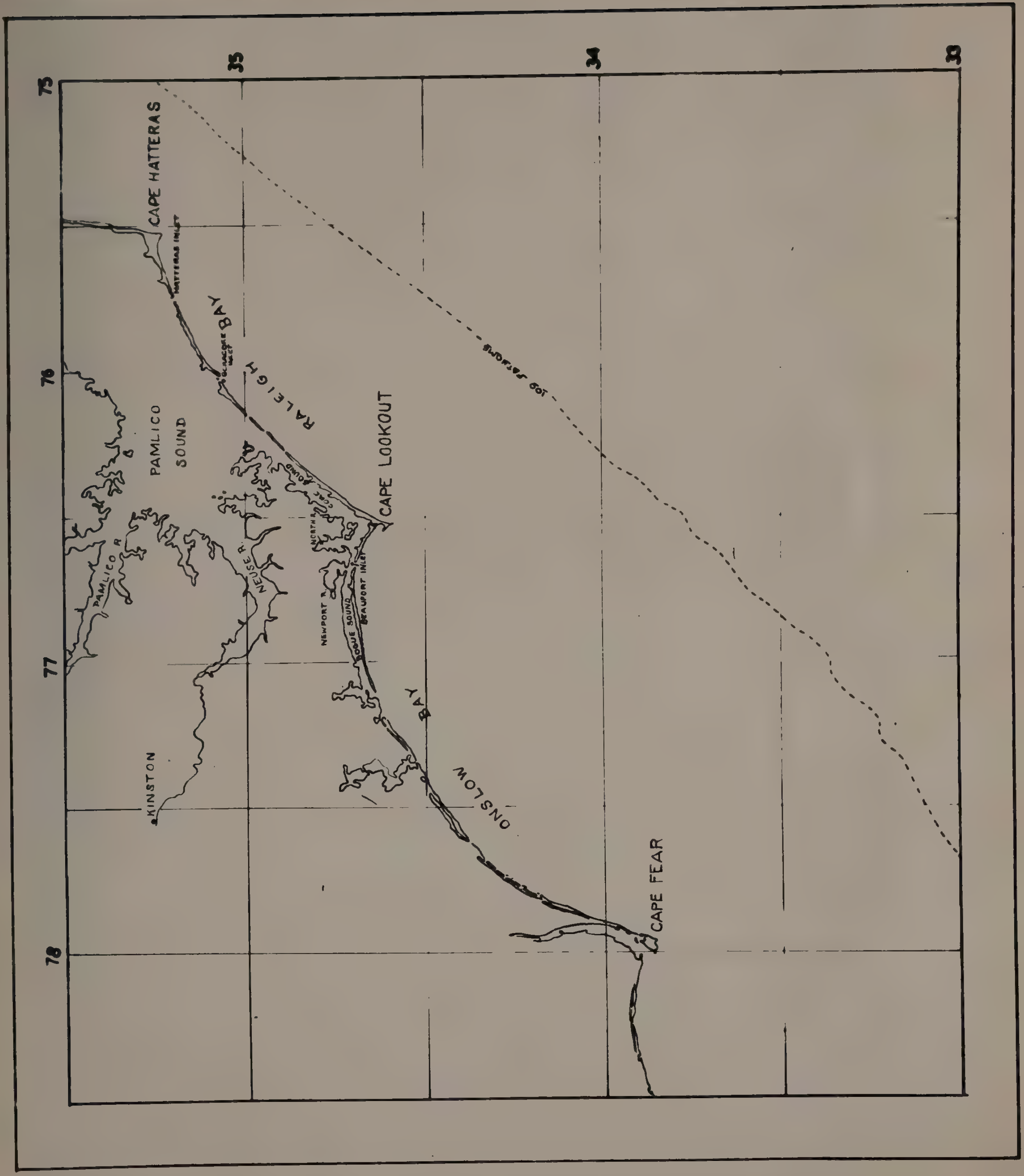


Figure 5. Averages of salinities coincident with temperatures. Numbers above columns indicate numbers of observations.

Since the salinity of Beaufort Inlet is lower than that of Onslow Bay (33-35o/oo), dilution by precipitation or land runoff is indicated. Inspection of Figure 7 of monthly precipitation totals at Morehead City (U.S. Department of Commerce, Weather Bureau 1947, 1948, 1949) and comparison with

Figure 6. Chart of localities in the Beaufort area.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CAPE HATTERAS
HATTERAS INLET
OCRACOKE INLET
RALEIGH BAY
PAMLICO SOUND
PAMLICO R.
NEUSE R.
CORE SOUND
NORTH R.
NEWPORT R.
BOGUE SOUND
BEAUFORT INLET
CAPE LOOKOUT
ONSLOW BAY
KINSTON
CAPE FEAR
100 FATHOMS

Figure 7. Monthly precipitation totals at Morehead City, North Carolina.

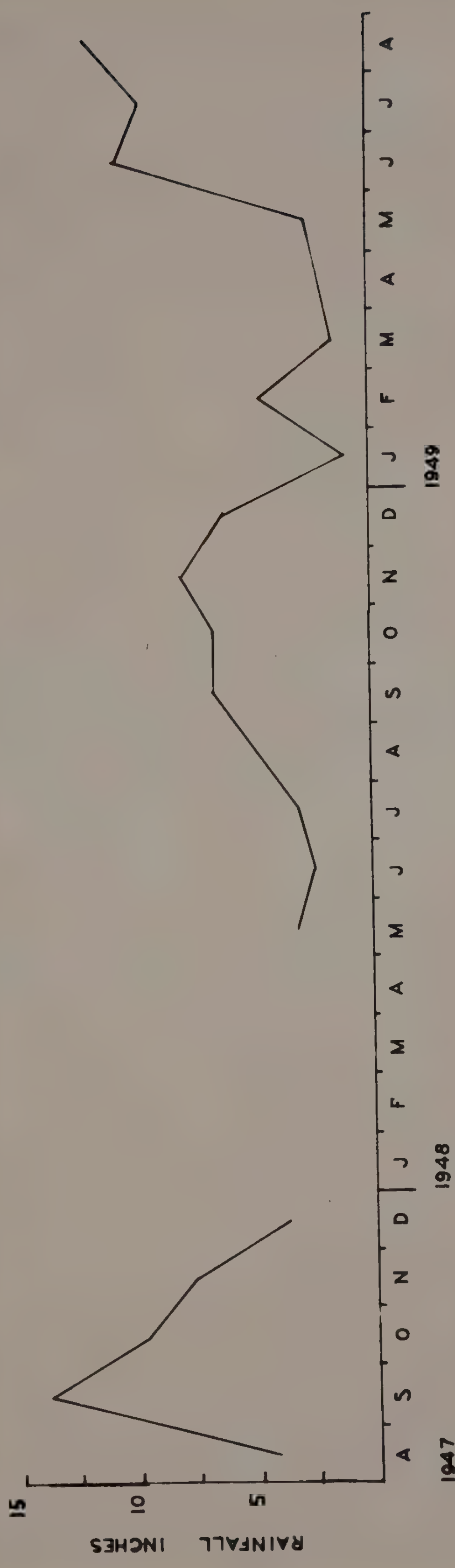
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Figure 4 shows that direct precipitation is not the major factor in salinity trends at Beaufort for the period of observation. Otherwise the salinity and precipitation would show closer correlations particularly in Septbmber 1947 and July and August 1949 when precipitation was highest.

In Figure 4 may be seen the water runoff values (monthly averages) for the Neuse River at Kinston, North Carolina (U.S. Geological Survey, personal communication). The runoff characteristics of the river at Kinston (60 miles from Beaufort) may possibly be somewhat similar to those of the North and Newport Rivers at Beaufort Inlet (Fig. 5). A relatively good correlation may be seen between times of low salinity and heaviest runoff. Perhaps a better comparison is the North East Cape Fear River which had almost exactly the same runoff characteristics as the Neuse except of course for volume (U.S. Geological Survey, personal communication). This river drains an area of approximately 600 square miles most of which lies within 50 miles of the ocean. All the area lies on the coastal plain. The recording station is at Chinquapin, North Carolina, about 68 miles west of Beaufort, but within 25 miles of the coast. A similar relationship was found by Beaven (1946) in Chesapeake Bay. The U.S. Geological Survey maintains no runoff recording stations nearer to Beaufort that that at Kinston.

Transparency

The question has been raised as to whether the Secchi disc

is an adequate method for the measure of water transparency. Poole and Atkins (1929) discussed the relative merits of this technique. They found that an estimate of the extinction coefficient could be determined by an application of the proper formula. Their findings were based on comparisons with photoelectric cell readings, and they recommend the use of the following: Extinction coefficient = 1.7/D, where D is the depth in meters at which the Secchi disc just disappears. Poole and Atkins point out that the visibility of the disc is independent of the illumination in air within wide limits because of the adaptability of the human eye to relative amounts of light. Bumpus and Clarke (1947) made further studies with the two methods of determining water transparency and found "good agreement" between photometer readings and Secchi disc observations. They verified the mathematical relationship between the two and used the above formula for conversion of Secchi disc measurements to extinction coefficients.

Figure 8 shows graphically the water transparency over the two-year period of observation. The following tidal differences in water transparency were found (extinction coefficient):

	Maxima	Minima	Averages(total)
High tide	3.09 Jan.2'48	0.46 May 31,'48	0.85
Low tide	2.23 Feb.22'48	0.47 Oct.17,'48	1.21

An average lower extinction coefficient for high tide indicates more transparent water. This is what might be expected, for at high tide there was presumably more ocean water (of greater transparency) present in the inlet.

[illegible]

[illegible] (1966) [illegible]

[illegible] They found [illegible]

[illegible]

[illegible] regulation, and they [illegible]

[illegible] diffusion coefficient = [illegible]

[illegible]

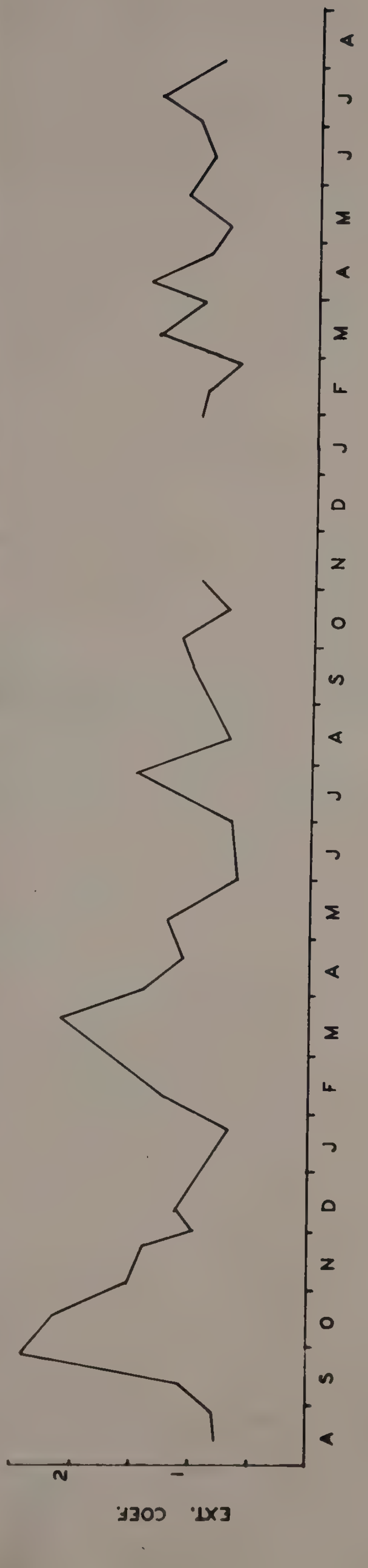
[illegible]

Figure 8 shows [illegible]

[illegible]

[illegible] in the inlet.

Figure 8. High and low tide averages of extinction coefficient.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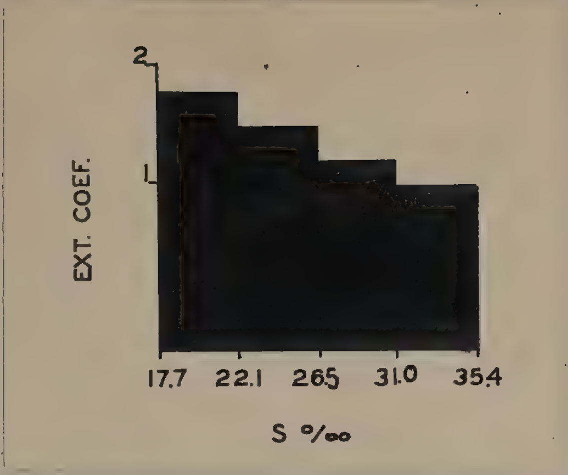


Figure 9. Averages of extinction coefficients coincident with salinities. Numbers above columns indicate numbers of observations.

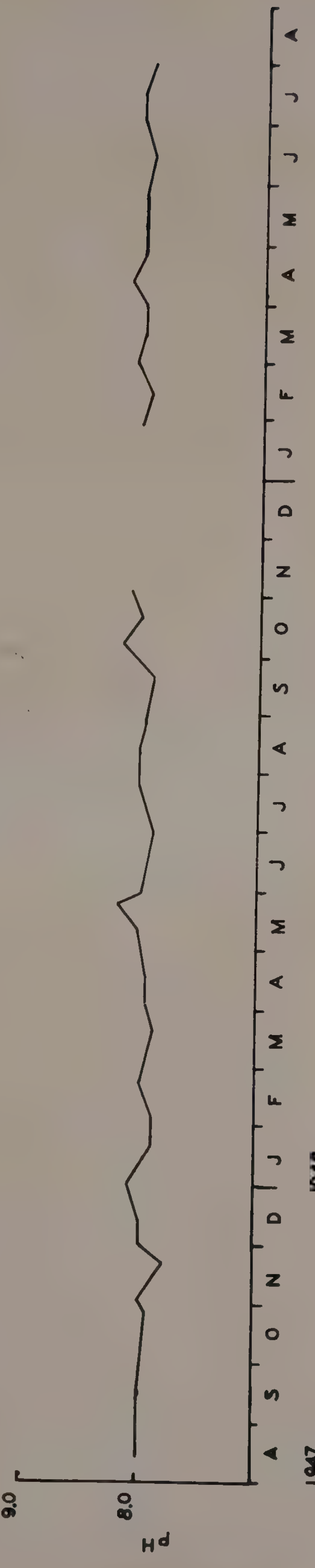
A correlation was found between salinity and transparency (Figure 9) in that water of higher salinity was on the average more transparent. The reason for this is possibly that water of higher salinity had a higher admixture of ocean water which is clearer than that in the sounds. Although the correlations were not as marked as those with salinity, higher values of extinction coefficient were generally coincident with higher temperatures.

It was found that winds blowing from west, north, or easterly directions (offshore) were generally accompanied by a decreased transparency, probably because of stirring up of local shallow waters. The reverse was true of winds blowing in from the ocean (southerly).

Hydrogen ion concentration

Figure 10 shows high and low tide averages of the pH encountered in Beaufort Inlet. These have been corrected for salt error according to Harvey (1945). The maxima, minima,

Figure 10. High and low tide averages of pH


pH
9.0
8.0
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1947
1948
1949

and averages of high and low tide observations are as follows:

	Maxima	Minima	Averages(total)
High tide	8.3 May 23,'49	7.9(5 occurrences)	8.0
Low tide	8.2 Oct.4,'48	7.5 Nov.20,'47	7.8

These ranges are within the limits given by Sverdrup et al. (1942) which are 7.5 to 8.4 for sea water. Harvey (1945) places these limits at 8.0 and 8.3 for open ocean, and indicates that deviations from these are found under special conditions such as shallow waters where variations of temperature and salinity are considerable.

Although the correlations were not clear, in general higher pH values were associated with greater transparency, higher salinity, and higher temperatures.

Oxygen

For a few months in 1949 the oxygen concentration was checked. Table II shows the results of these observations.

Date	Tide	O_2ml/l	% Saturation
May 6	High	5.12	97
May 7	Low	4.56	85
May 23	Low	4.72	93
May 23	High	4.96	96
June 13	High	4.72	93
June 14	Low	-	-
June 30	Low	4.00	84
July 2	High	4.80	97
July 15	High	4.48	96
July 15	Low	4.36	92
Aug. 1	High	4.32	94
Aug. 2	Low	3.63	78

Table II. Observations on the concentration of O_2 in 1949. Beaufort Inlet.

It will be noted that the percent saturation was

relatively high, as would be expected of surface water in more or less constant contact with the atmosphere.

Related Areas

Bogue Sound

Table III shows conditions which occurred with some plankton tows made for a few months in 1949 at the pier of the University of North Carolina Institute of Fisheries Research.

Tow No.	Date	Tide	Water Temp. °C	Salinity o/oo	Ext. Coef.
1	March 15	Low	12.3	29.8	0.71
2	March 28	Low	17.7	31.6	0.77
3	April 13	Low	20.5	30.3	2.13
4	April 21	High	18.9	32.9	1.06
5	April 21	Low	18.4	32.4	1.31
6	May 11	-	21.9	30.5	0.94
7	June 17	Low	24.2	29.2	1.21
8	June 20	Low	27.9	28.4	1.42
9	June 20	High	28.6	29.0	1.70

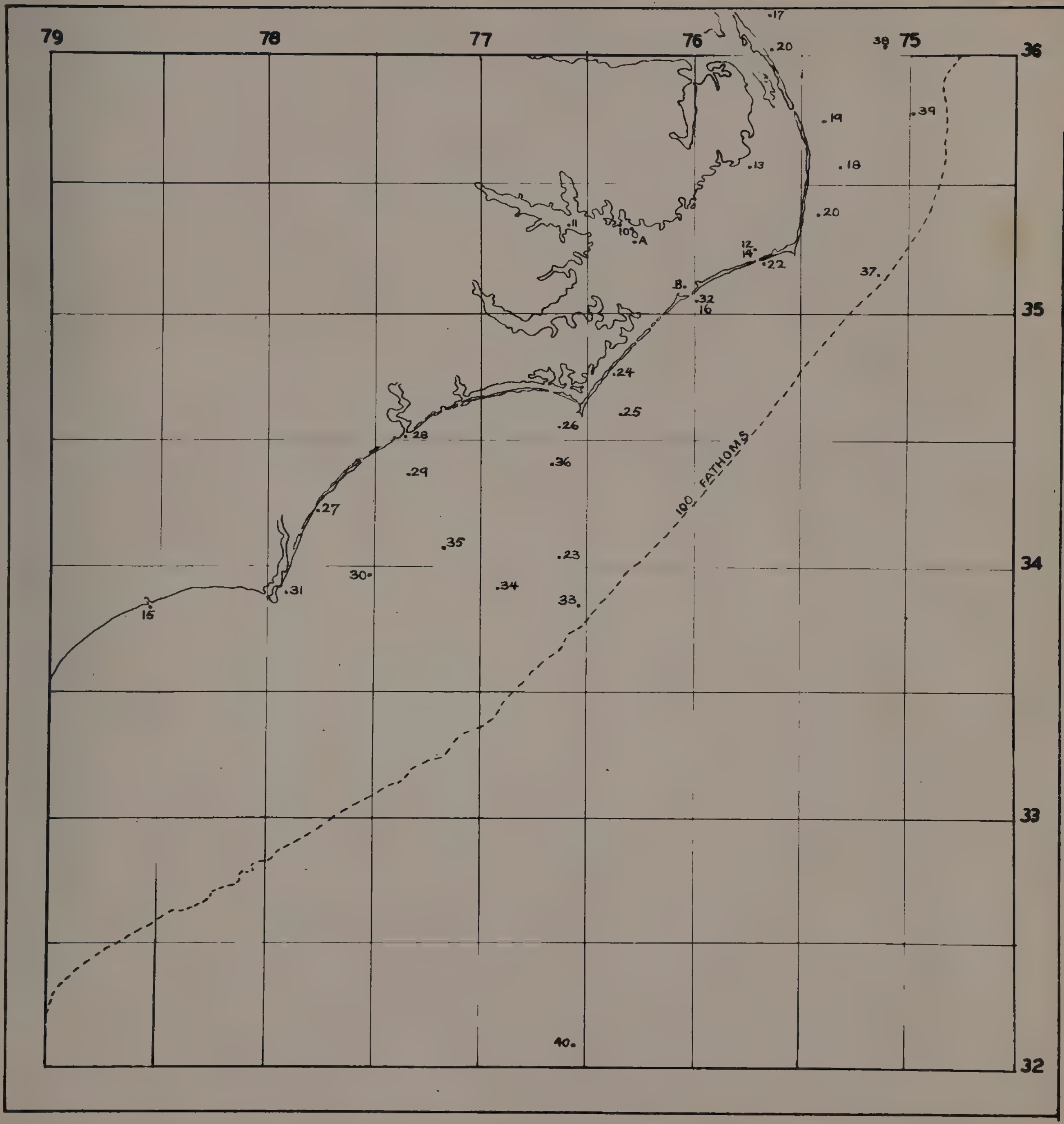
Table III. Some hydrographic conditions observed with plankton tows taken at the pier of North Carolina Institute of Fisheries Research. 1949.

Pamlico Sound

To give some idea of the hydrographic conditions encountered in Pamlico Sound, data are given from two stations (A and B, Figure 11) in Tables IV and V.

If the salinities are compared with those obtained at Beaufort Inlet, it may be seen that those found in Pamlico Sound are considerably lower. Some readings taken in the mouth of the Pamlico River were as low as 3 or 4 o/oo.

Figure 11. Chart showing locations of tow numbers and stations.


79
78
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75
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20
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10
A
12
14
22
37
B
32
16
24
25
26
28
36
29
27
35
23
30
34
31
33
15
40
100 FATHOMS

Date	Temp. °C	Salinity o/oo	Ext. Coef.	pH
June 16, 1948	26.0	10.8	1.06	-
July 13, 1948	27.2	14.1	1.00	-
Aug. 16, 1948	27.0	17.6	1.31	8.1
Sept. 16, 1948	24.5	20.3	1.21	8.0
Oct. 14, 1948	19.6	16.8	0.81	-
Dec. 8, 1948	14.8	8.0	1.21	-
Dec. 18, 1948	11.8	14.3	0.74	-
Jan. 19, 1949	10.5	7.7	1.13	-
Mar. 2, 1949	8.7	8.7	2.13	-

Table IV. Hydrographic conditions found near Judith Island, Pamlico Sound, North Carolina (Sta.A, Fig.1D).

Date	Temp. °C	Salinity o/oo	Ext. Coef.	pH
Aug. 18, 1948	27.8	21.3	0.85	8.1
Sept. 6, 1948	25.7	22.4	0.89	8.1
Mar. 3, 1949	9.0	14.2	2.13	-
April 14,1949	17.7	19.1	1.42	-
June 3, 1949	20.2	18.2	3.40	-
June 28, 1949	28.4	16.6	1.21	-

Table V. Hydrographic conditions found just inside Ocracoke Inlet, Pamlico Sound, North Carolina (Sta. B, Fig. 1D).

Others taken near the inlets were also relatively low, depending on the stage of the tide. Observations have been recorded (1949) as low as 14.6 inside from Hatteras Inlet in March and June; and as low as 12.8, 15.2, and 16.6 March, April, and June, respectively inside from Ocracoke Inlet. Bottom salinities with few exceptions were within 2 or 3 o/oo of surface salinities, and usually higher. The salinities of Pamlico Sound were lower than those of Beaufort Inlet and Bogue Sound, because of the much more extensive drainage of the Pamlico and Neuse Rivers as may be seen in Figure 5. Observations

taken in 1948 and 1949 indicate that the salinities generally become higher as one proceeds from Pamlico Sound to Beaufort Inlet through Core Sound.

Table VI gives hydrographic conditions observed with plankton samples examined from Pamlico Sound (See Fig. 11).

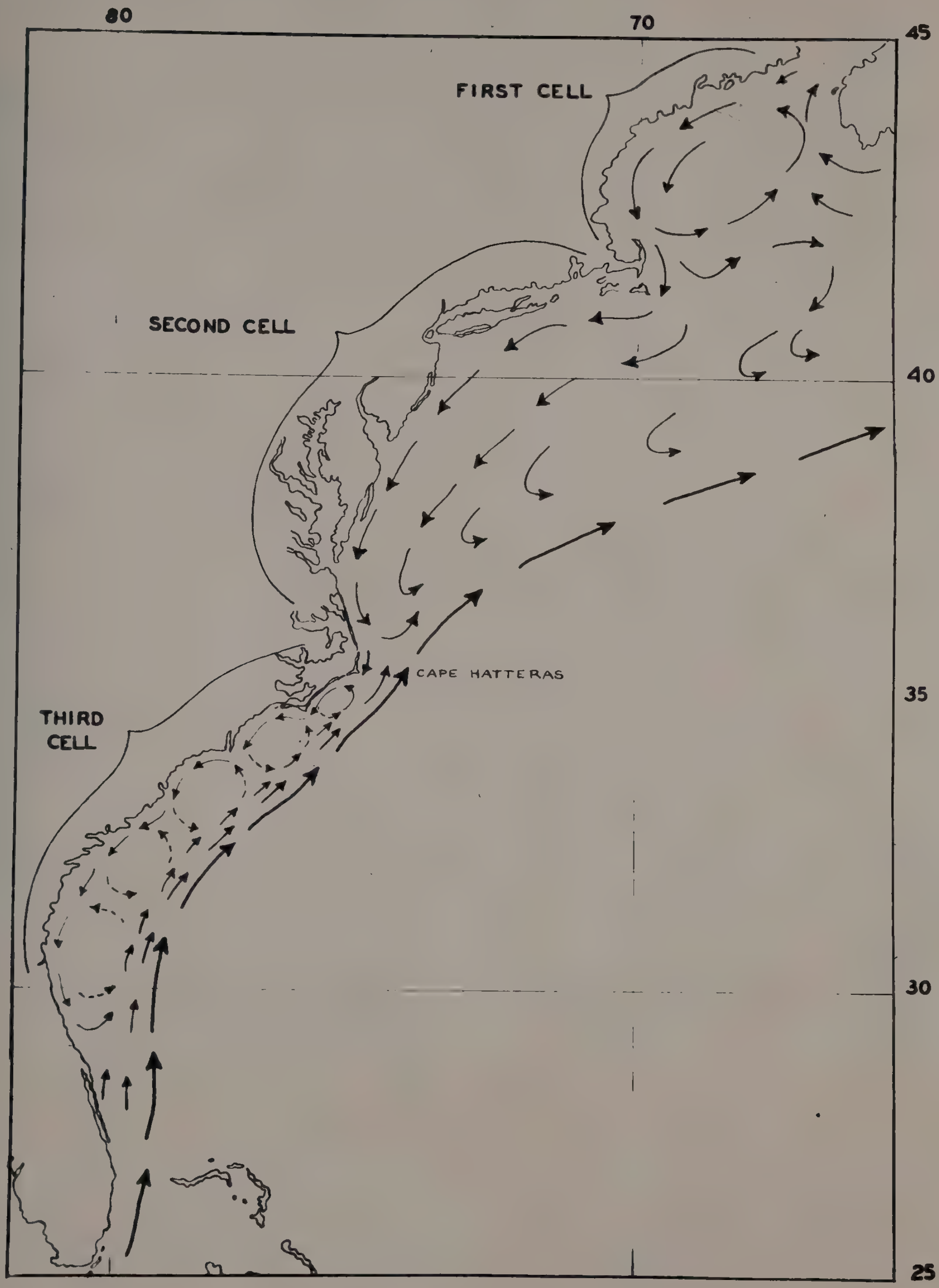
Tow No.	Date	Temp. °C	Salinity o/oo	Ext. Coef.
10	Mar.2,1949	7.1	9.6	1.21
11	Mar.2,1949	8.8	4.9	3.40
12	June 28,1949	28.5	17.0	1.13
13	July 12,1949	28.3	16.5	1.31
14	July 12,1949	28.1	18.4	1.06

Table VI. Hydrographic conditions existing with plankton samples taken in Pamlico Sound, North Carolina (See Fig. 11).

Outside

Bumpus and Wehe (1949) give the results of recent hydrographic investigations off the Atlantic Coast and, on the basis of their evidence, hypothesize the water circulation as shown in Figure 12. Further hydrographic work in May and June of 1949 by the Albatross III of the U.S. Fish and Wildlife Service (data as yet unpublished) supports this thesis. (Bumpus private communication). The peculiar configurations of isotherms and isohalines thought to be caused by eddies in Raleigh and Onslow Bays (Bumpus and Wehe 1949) are readily apparent in the more recent data. It will be noted that the Gulf Stream[2] (heavy arrows) swings off shore from

Figure 12. Schematic diagram of coastal circulation. (taken from Bumpus and Wehe 1949).


80
70
45
40
35
30
25
FIRST CELL
SECOND CELL
THIRD CELL
CAPE HATTERAS

Cape Hatteras and a coastwise counter current (cold) runs down close to shore in "cell two" from New England to Cape Hatteras. At this point the counter current may swing around as an eddy, or, as has been thought, may come around Cape Hatteras and be carried by small eddies in Raleigh and Onslow Bays farther down the Carolina coast. However, whether or not the circulation around Cape Hatteras is a continuous one or a seasonal or sporadic one is not yet definitely established.

Temperature readings taken just north and east of Cape Hatteras in May or June 1949 indicate that for this particular time there was little or no colder water going around Cape Hatteras. The "limit" to the cold water apparently lay about 10 miles north of Cape Hatteras; temperature readings taken south of this point ranged around 23°C, while those to the northward were in the vicinity of 16°C. Temperature observations taken near the line of demarcation (tow 39) showed distinct stratification of the two water masses of different temperature. The upper layer was around 24°C and the bottom layer around 16°C. The line of stratification was sharp, encompassing some 15 feet of water in a total depth of about 190 feet. The upper (warmer) layer was about twice the thickness of the lower.

A few scattered surface observations taken by the investigators of the Institute of Fisheries Research aboard the Penny

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[2] Sverdrup et al. (1942) term this offshore northward-flowing current the "Florida Current" as far as Cape Hatteras. From this point northward they call it the Gulf Stream.

close to shore and north of Cape Hatteras late in March 1949 showed temperatures ranging from 10°C to 14.8°C. Farther down the coast in Raleigh Bay the surface temperatures were found to vary from 12-16°C. These relative similarities in temperatures at least do not preclude the possibility of the continuity of water of somewhat similar origin north and south of Cape Hatteras. This point will be discussed again with respect to the plankton.

The prevailing winds during the warmer months in the Cape Hatteras area have been found to be (1942,1948,1949) of a southerly or southwesterly direction (U.S. Weather Bureau at Cape Hatteras, personal communication). Those in the winter are from a north or northeasterly direction. It is possible that winds influence water circulation around Cape Hatteras and thus assist an influx of northern cold water into Raleigh and Onslow Bays from Cape Hatteras in winter, and prevent such circulation in summer.

In the spring of 1948 and early summer of 1949 temperatures and salinities were found to decrease gradually from the Gulf Stream shoreward. The maxima in surface temperatures found in the Gulf Stream were from 23°C in March 1948 (Bumpus and Wehe 1949) to 27.2°C in June 1949 (unpublished data from Albatross III).

Some of the hydrographic observations accompanied by plankton tows taken on the Carolina coast from the Penny and the Albatross III are summarized in Table VII.

Tow No.	Date	Surface Temp. °C	Surface Salinity o/oo	Type of Tow
Penny				
15	Feb.21,1949	-	-	surface
16	Mar.15,1949	12.8	-	"
17	Mar.24,1949	10.5	30.1	"
18	Mar.28,1949	12.3	32.0	"
19	Mar.28,1949	10.5	31.5	"
20	Mar.29,1949	10.7	30.7	"
21	Mar.30,1949	14.8	29.6	"
22	Mar.31,1949	16.3	28.9	"
23	Apr.4,1949	23.4	36.1	"
24	Apr.7,1949	-	-	"
25	Apr.7,1949	16.2	34.9	"
26	Apr.18,1949	15.2	34.3	"
27	Apr.20,1949	-	-	"
28	Apr.20,1949	-	-	"
29	Apr.20,1949	16.3	-	"
30	Apr.21,1949	19.2	35.2	"
31	Apr.27,1949	-	-	"
32	July 12,1949	27.1	27.1	"
Albatross III				
33	May 24,1949	26.5	36.2	vertical-90fm
34	May 24,1949	23.2	35.3	" -19"
35	May 24,1949	22.5	35.8	" -10"
36	June 7,1949	24.8	-	" -11"
37	June 9,1949	26.4	36.2	" -50"
38	June 2,1949	16.0	-	" -16"
39	June 2,1949	25.3	-	" -30"
40	May 26,1949	25.2	36.2	" -360"

Table VII. Hydrographic conditions observed with plankton tows taken off the Carolina coast (see Figure 11).

BIOLOGICAL OBSERVATIONS

Beaufort Inlet

Diatoms

Diatoms were counted as an indication of the fluctuations of the phytoplankton. Some diatoms were too small to be retained by the net size used, and for this reason diatom counts have only a relative value. The average of all samples was 776,507 cells per cubic meter.

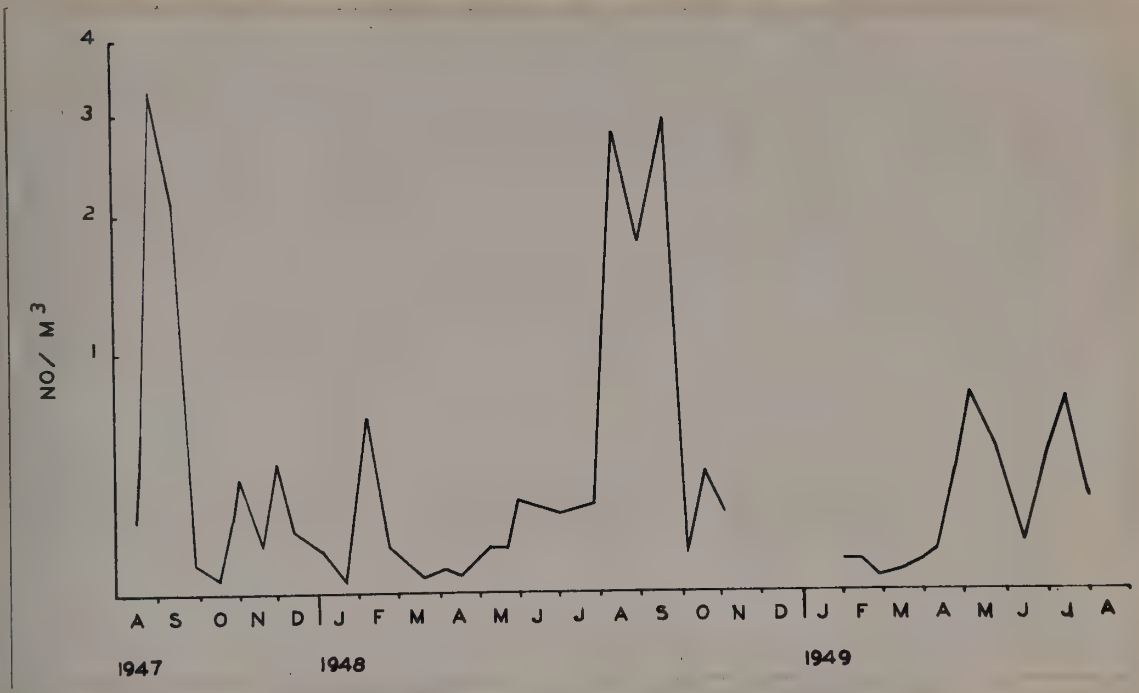
Figure 13 shows the distribution of diatoms with respect to the period of observation. It may be seen that diatoms were more numerous during the summer and fall than during the winter. It may be seen from Figure 14 that diatoms were most numerous at higher temperatures with a secondary peak during colder weather. Figure 15 shows that greatest numbers were encountered at the highest salinities.

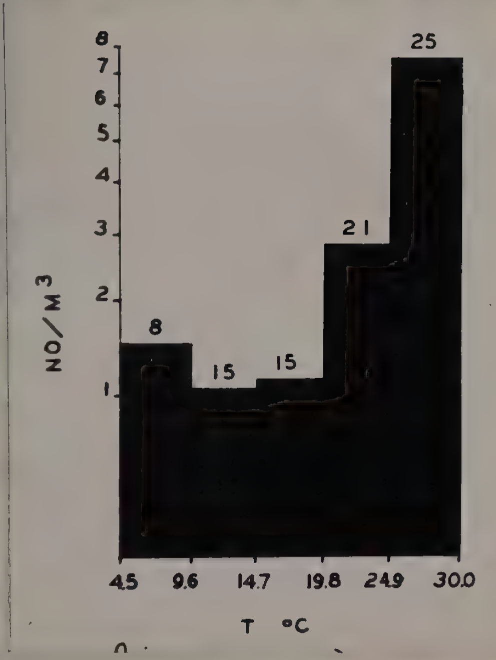
A positive correlation between diatoms and transparency was found (Fig. 16). Diatoms were most numerous in the clearest water indicating that they were probably contributing very

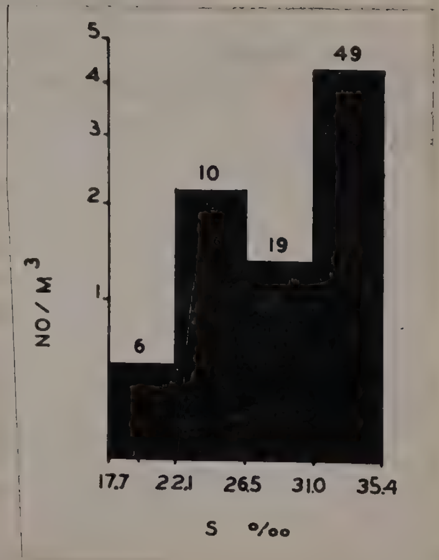
Figure 13. High and low tide means of diatoms. No/m^3 in millions.

Figure 14. Means of diatoms with ranges of temperature. Numbers above columns indicate number of observations. No/m^3 in hundreds of thousands.

Figure 15. Means of diatoms with ranges of salinity. Numbers above columns indicate number of observations. No/m^3 in hundreds of thousands.


4
3
2
1
NO/ M³
A S O N D J F M A M J J A S O N D J F M A M J J A
1947
1948
1949


8
7
6
5
4
3
2
1
NO/M³
8
15
15
21
25
4.5 9.6 14.7 19.8 24.9 30.0
T °C


5
4
3
2
1
NO/M³
6
10
19
49
17.7 22.1 26.5 31.0 35.4
S °/oo

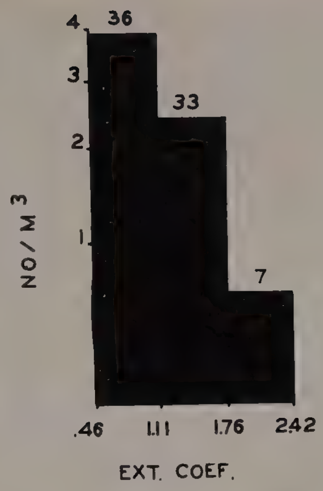


Figure 16. Means of diatoms observed with ranges of extinction coefficient. No/m^3 in hundreds of thousands. Value 3.09, omitted from graph, accompanied by 165,300/m^3.

little to the opacity. Poole and Atkins (1929) failed to find any very noticeable effect of the spring diatomsbloom on transparency near Plymouth, England. (In view of the concurrence of salinity and transparency, as can be seen in Figure 9, it is possible that the apparent correlation of diatoms with transparency is merely a coincidence.) On the other hand, Rees (1939) points out that opacity might cut down production of diatoms, thus resulting in lower diatom populations at times of greater turbidity.

Table VIII shows means of diatoms at various values of pH. According to Sverdrup et al. (1942) periods of high diatomsproduction are sometimes accompanied by a marked rise in pH as a result of utilization of carbonic acid by the plants. No such correlation is clearly evident in Table VIII.

Means No/m^3	pH	Number Observations
75,370	<7.9	4
330,800	7.9	20
303,800	8.0	37
324,300	8.1	14
152,200	>8.1	4

Table VIII. Means of diatoms observed with values of pH.

More diatoms were found at high tide (287,470/m^3) than at low tide (226,660/m^3). Each mean is composed of 42 observations.

Total zooplankton

A graph of the total zooplankton (Fig. 17) shows that, in general, during the period of study, the populations were higher during the summer and fall, and lower during the winter. An average of 12,217 animals per cubic meter was found (No. 10 net) for the entire period of time. This may be compared with an average of 1,740/m^3 obtained by Riley (1938) at Dry Tortugas with a No. 20 net, and with an average of 69,000/m^3 by Riley and Bumpus (1946) on Georges Bank with a No. 2 net. From these figures it appears that zooplankton occurrences at Beaufort Inlet lie between that of tropical and northern regions, but much nearer the tropical.

In Figures 18 and 19 it may be seen that zooplankton counts were much greater at high temperatures and high salinities. A positive correlation with transparency was found for zooplankton (Figure 20) as with diatoms. It is possible that

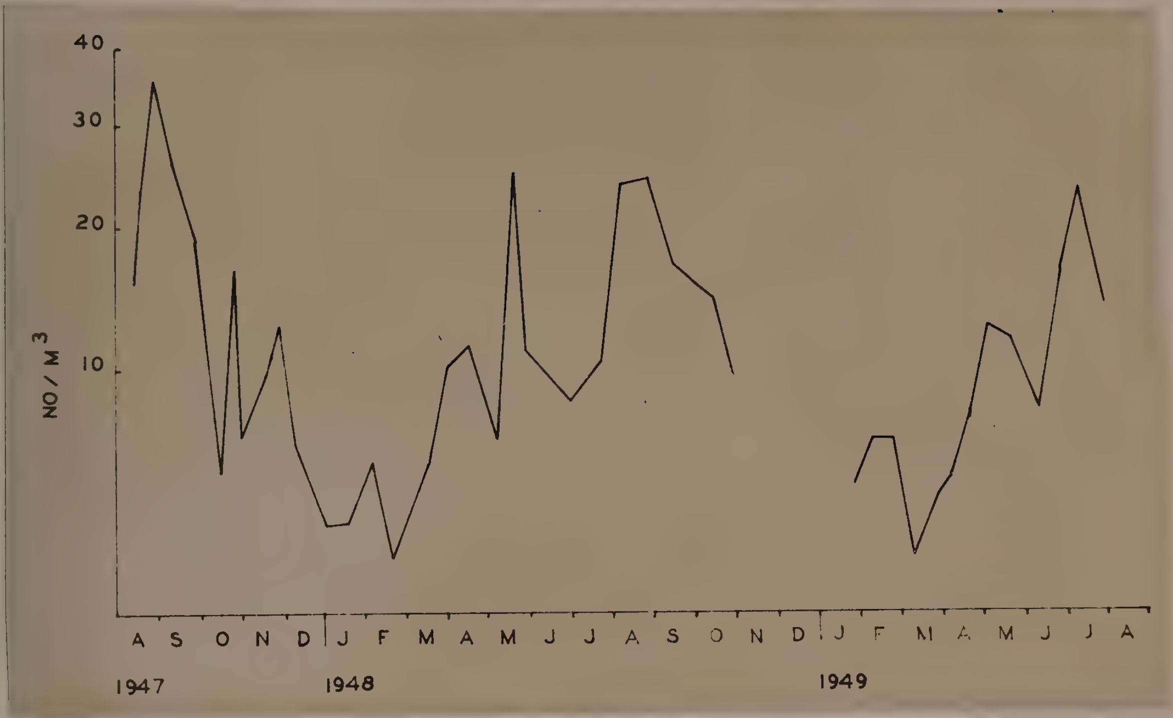


Figure 17. High and low tide means of total zooplankton. No/m^3 in thousands.

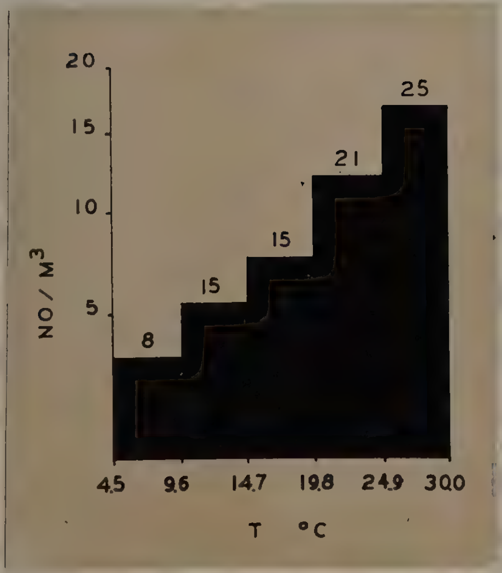


Figure 18. Means of total zooplankton with ranges of temperature. Numbers above columns indicate number of observations. No/m^3 in thousands.

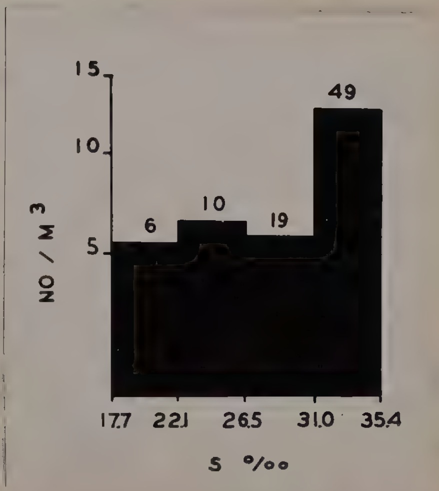


Figure 19. Means of total zooplankton with ranges of salinity. Numbers above columns indicate number of observations. No/m^3 in thousands.

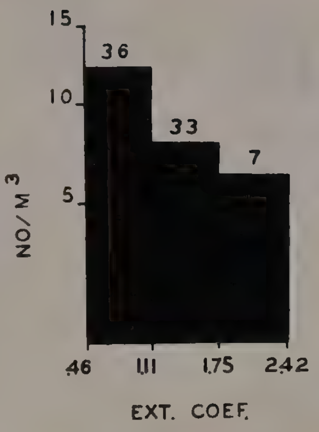


Figure 20. Means of zooplankton observed with ranges of extinction coefficient. No/m^3 in thousands. Value of 3.09, omitted from graph, accompanied by 3042/m^3.

this correlation may be a function of salinity, as more transparent water and higher salinities were coexistent. (Fig. 9). At any rate, all the zooplankton groups studied, showed a positive or negative correlation with the transparency depending on the correlation with salinity. No correlations were apparent between time of day and total zooplankton to indicate vertical migrations. Peaks of abundance of diatoms and zooplankton generally coincided.

The percentage composition of the total zooplankton was found to be as shown in Table IX. The remainder from Table IX was composed of small numbers of isopods, ostracods, pelagic tunicates, pelagic decapods, cumaceans, and siphonophores. The various groups comprising the total zooplankton will be taken up in order of numerical importance. Most of the groups discussed in the following pages are composites of a number

Organisms	Average No/m^3	% total Zooplankton
Copepods, copepodids	7272	59.52
Copepod nauplii	2542	20.80
Pelecypod larvae	758	6.20
Annelid larvae	380	3.11
Cladocerans	334	2.74
Barnacle larvae	272	2.23
Gastropod larvae	191	1.56
Tunicate larvae	169	1.38
Echinoderm larvae	105	0.86
Decapod, stomatopod larvae	101	0.83
Chaetognatha	51	0.42
Nematodes	15	0.12
Medusae	13	0.11

Table IX. Average number per cubic meter and percent composition of the groups comprising the total zooplankton.

of species; only a few of the groups have been segregated to individual species. For this reason ecological data and observations on copepods and other groups in which species are discussed have more significance.

Means No/m^3	pH	Number Observations
4,650	<7.9	4
8,464	7.9	20
8,671	8.0	37
12,710	8.1	14
16,424	>8.1	4

Table X. Means of total zooplankton observed with values of pH.

Numbers of the total zooplankton occurring with values of pH are shown in Table X. The total zooplankton mean was higher for high tide than for low tide: high-10,938/m^3; low-7,900/m^3.

Total copepods

Copepods generally were found to be more numerous in summer than in winter as may be seen in Figure 21. Correlations with temperature and salinity are shown in Figures 22 and 23. No correlations were found with time of day. Copepods were more frequently encountered at high tide (6,847/m^3) than at low tide (4,016/m^3). Numbers of copepods occurring with pH are shown in Table XI. A partial breakdown of the percentage compostion of the total copepods is shown in

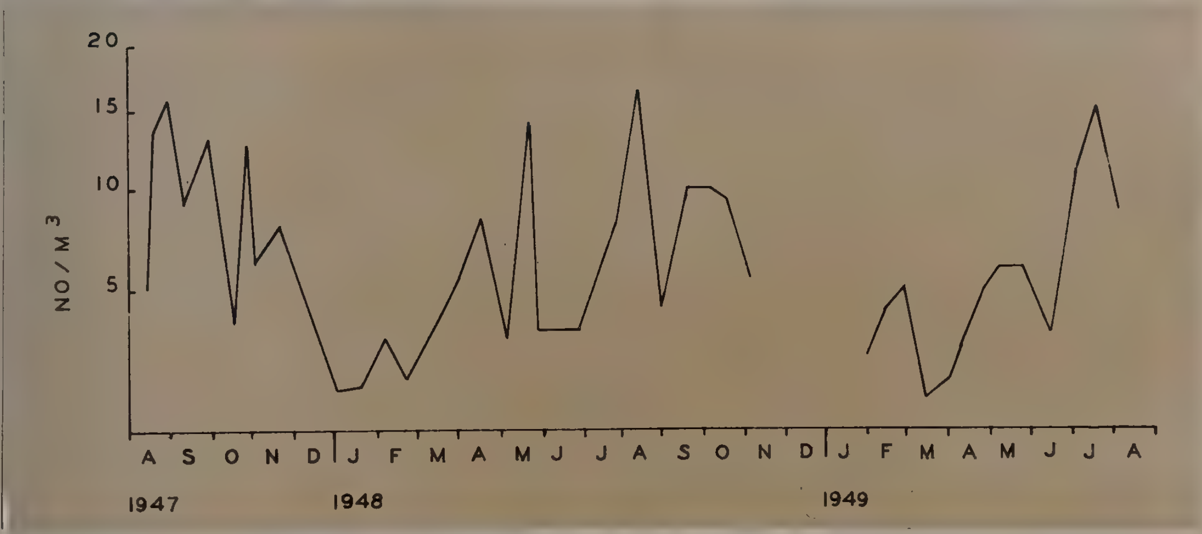


Figure 21. High and low tide means of total copepods counted during period of observation. No/m^3 in thousands.

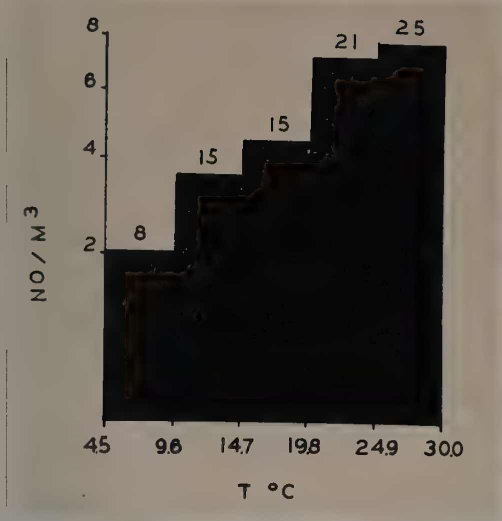


Figure 22. Means of total copepods observed with ranges of temperature. No/m^3 in thousands.

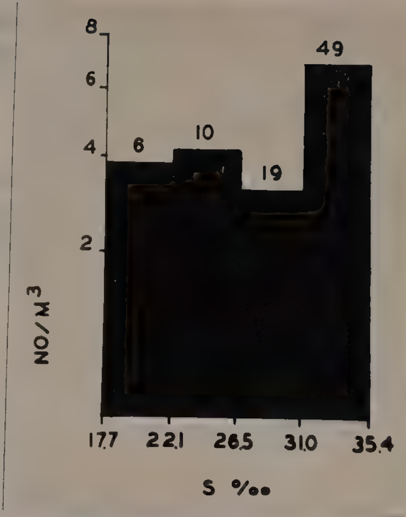


Figure 23. Means of total copepods observed with ranges of salinity. No/m^3 in thousands.

Means No/m^3	pH	Number Observations
3,649	<7.9	4
3,928	7.9	20
5,601	8.0	37
14,310	8.1	14
3,842	>8.1	4

Table XI. Means of total copepods observed with values of pH.

Table XII.

In the following discussions, copepodid stages recognizable as belonging to a given species, as well as the adults are included.

	Means No/m^3	% Total Copepods
Calanoids	4202	57.78
Cyclopoids	2740	37.69
Harpacticoids	330	4.53

Table XII. Average numbers per cubic meter and percent composition of the three groups of total copepods.

Acartia tonsa Dana[3]. Acartia tonsa was one of the few copepods found to be present in considerable numbers at all times of the year. The distribution with respect to the time covered by the study may be seen in Figure 24. This species was well represented in most of the temperature classes (Fig. 25) but showed an inverse relationship to salinity (Fig. 26).

A slight correlation with time of day was found for this species in that higher numbers were encountered toward midday, when the amount of light was greatest. Numbers of A. tonsa occurring with pH are shown in Table XIII. A considerably higher mean was found at low tide (1,064/m^3) than at high tide (927/m^3).

Acartia tonsa was found to be the dominant copepod in Bogue Sound and occurred in tows 1-5, and 9 (Table III). In Pamlico Sound Acartia was also the dominant copepod and was found in tows 10-14 (Table VI, Fig. 11). In the ocean

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[3] There is reason to believe that the name of the Atlantic species of Acartia now called A. tonsa should be A. giesbrechti Dahl, 1894. This will be presented in a subsequent paper.

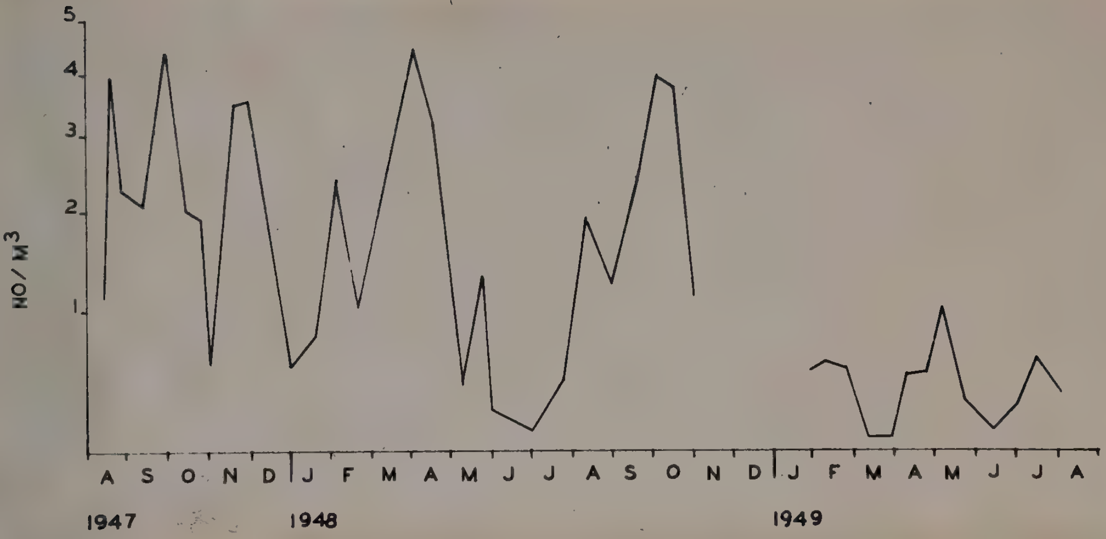


Figure 24. High and low tide means of *Acartia tonsa*. No/m³ in thousands.

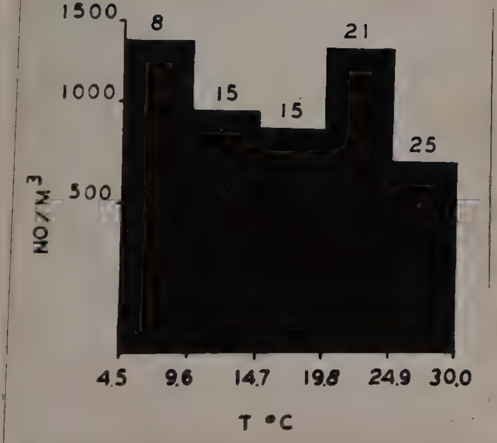


Figure 25. Means of *Acartia tonsa* with ranges of temperature.

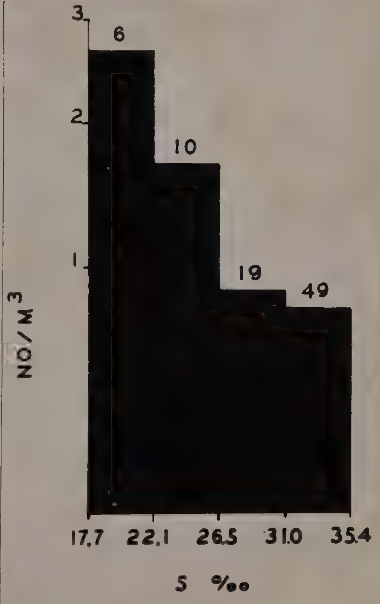


Figure 26. Means of *Acartia tonsa* with ranges of salinity. No/m³ in thousands.

Acartia was found in tows 15, 16, 20, 23-25, 27, 28, 31, and 32.(Table VII, Fig. 11).

Means No/m^3	pH	Number Observations
1,802	<7.9	4
1,010	7.9	20
5,934	8.0	37
2 982	8.1	14
1,495	>8.1	4

Table XIII. Means of *Acartia tonsa* observed with values of pH.

The occurrences listed at Beaufort Inlet and related areas for *A. tonsa* covered a wide range of temperatures (5.0-29.4°C) and salinities (4.6-35.4o/oo) in all seasons. It occurred relatively near shore in every case but in tow 23.

Acartia tonsa has been reported from Woods Hole by Bigelow (1926) and Fish (1925). It is common in brackish water ponds as well as ocean water near shore in that region (Bigelow 1926) and since Fish found it from June to November he regarded it as a summer form. Davis (1944) reported *A. tonsa* as one of the dominant species in Chesapeake Bay. He found it in both summer and winter and in salinities approaching those of fresh water (chlorinity 0.4o/oo). Davis (unpublished data) has also recorded this species from south Florida where it is conspicuously absent from the Gulf Stream.

In view of the above considerations, it might seem that *A. tonsa* is able to tolerate the relatively wide ranges of

conditions found at Beaufort Inlet with respect to temperature and salinity.

Centropages furcatus (Dana). This species (called C. typicus by Sutcliffe 1948(was most frequently found in the summer and fall, (Fig. 27) and at high temperatures and salinities (Fig. 28 and 29). Greater numbers were found at high tide (15/m^3) than at low tide (4.8/m^3). Numbers occurring with pH are Table XIV.

Means No/m^3	pH	Number Observations
1.9	<7.9	4
8.5	7.9	20
6.6	8.0	37
26	8.1	14
12	>8.1	4

Table XIV. Means of Centropages furcatus observed with values of pH.

Centropages furcatus was found in tow 9 in Bogue Sound (Table III) but not in any of the Pamlico Sound tows, possibly because of the low salinities. Outside it occurred in tows 31-37 (Table VII, Fig. 11).

This species is thought to be a tropical form, which occurrs in the Gulf of Mexico (Davis, unpublished data, and Mr. Paul L. Illg, private communication), off the Florida Keys (Davis, unpublished data), near the Amazon River (Dahl 1894). Cleve (1900) has reported C. furcatus from the tropical Atlantic.

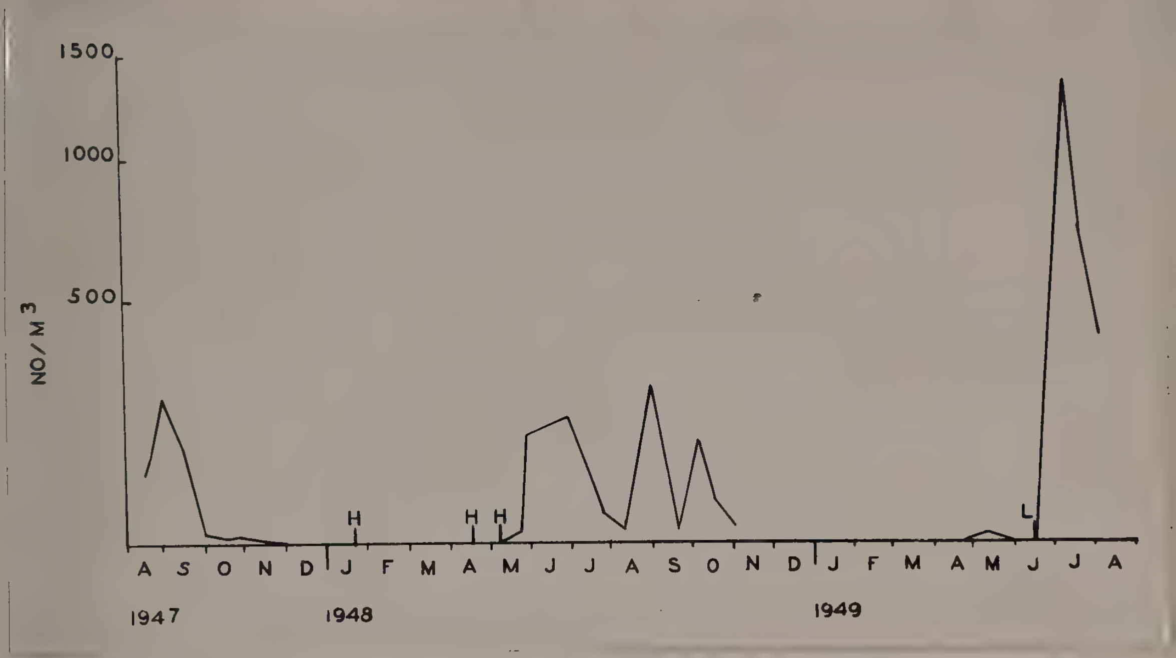
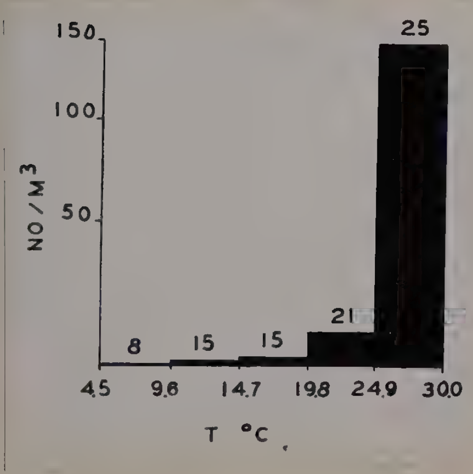


Figure 27. High and low tide means of *Centropages furcatus*. Letters H or L refer to presence at high or low tide.



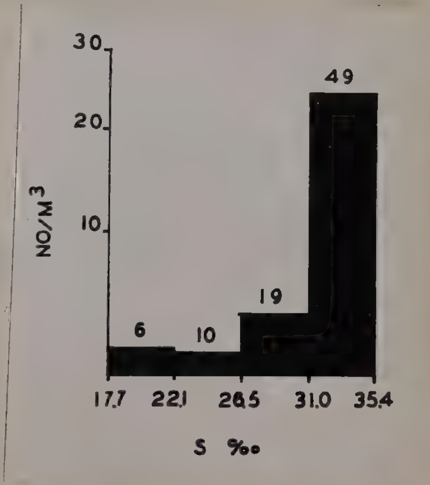


Figure 28. Means of *Centropages furcatus* with ranges of temperature.

Figure 29. Means of *Centropages furcatus* with ranges of salinity.

Centropages furcatus was found to be mainly a summer plankton constituent at Beaufort. It was most probably brought north by the Gulf Stream and shunted in by the eddies as shown in Figure 12. It would appear that extremes in temperature and salinity at Beaufort make the survival of this species difficult over the winter in the adult form. No copepodid stages of *C. furcatus* were seen during the winter months.

Centropages hamatus (Lilljeborg). This copepod was found in the colder months of the year and was most numerous in the spring (Fig. 30). Greatest numbers were found at lower temperatures and salinities (Figs. 31 and 32). Numbers of *C. hamatus* occurring with pH are shown in Table XV. This form occurred in greater numbers at low tide (4.5/m^3) than at high tide (3.1/m^3).

Means No/m^3	pH	Number Observations
18	<7.9	4
3.7	7.9	20
4.3	8.0	37
1.9	8.1	14
4.0	>8.1	4

Table XV. Means of *Centropages hamatus* observed with values of pH.

Centropages hamatus was not found in any of the Bogue Sound or Pamlico Sound tows. It occurred in tows 15 and 20 (Table VII, Fig.11) of the outside material. These

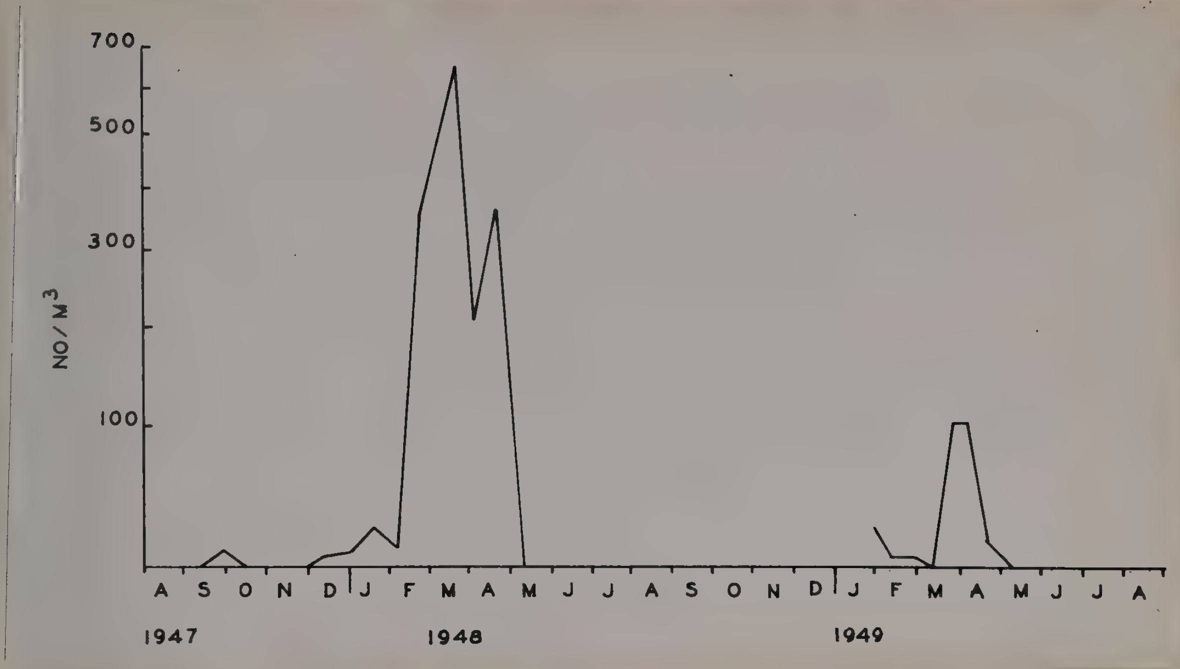
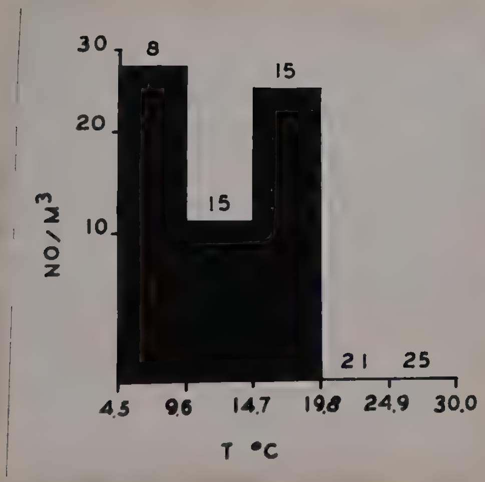


Figure 30. High and low tide means of Centropages hamatus.



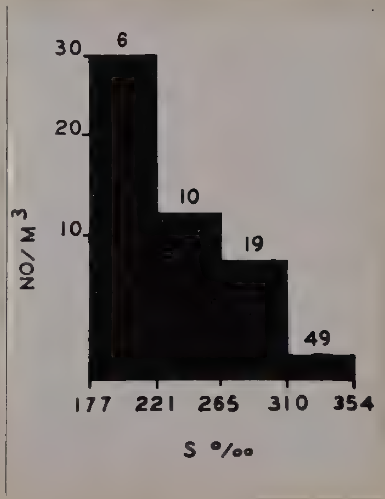


Figure 31. Means of Centropages hamatus with ranges of temperature.

Figure 32. Means of Centropages hamatus with ranges of salinity.

occurrences are in accord as to season with the findings at Beaufort Inlet where it was found mainly in winter and spring.

Bigelow (1926) lists this copepod as fairly common in the Gulf of Maine in fall and early winter. He states that it is a neritic rather than an oceanic form. Fish (1925) lists *C. hamatus* as occurring from August to May, and terms it a true cold water form. Wilson (1932a) found it common in Chesapeake Bay where it was mainly a winter and spring species.

Centropages hamatus may be regarded as a cold temperate or northern species at Beaufort in view of the geographical distribution and lack of adults in the warm months of the year. This brings up the question of possible survival during the summer in an early developmental stage. *Calanus finmarchicus* has been found to pass through the developmental stages from egg to adult in four weeks (Nicholls 1933), this being somewhat dependent on temperature. However, under unfavorable conditions Calanus may remain in the fifth copepodid stage for several months (Johnson and Olson 1948). If *Centropages hamatus* can be compared to *Calanus finmarchicus* in developmental cycle, it is unlikely that it could have summered over at Beaufort in a developmental stage, for no copepodid stages of Centropages were found during the summer other than those of *C. furcatus*. Clarke (Galtsoff et al. 1937) found that *C. hamatus* from Woods Hole died off rapidly if the water temperatures were raised above 20°C.

Centropages typicus Krøyer. This species (as with *C. hamatus*) was found mostly in spring and late winter as shown in Figure 33. Highest populations were found in the 9.6-14.6°C range of temperature (Fig. 34); numbers occurring with ranges of salinity are shown in Figure 35. More individuals were found at high tide (4.4/m^3) than at low tide (3.2/m^3). Means occurring with values of pH are given in Table XVI.

Means No/m^3	pH	Number Observations
5.8	<7.9	4
2.3	7.9	20
5.1	8.0	37
5.2	8.1	14
2.6	>8.1	4

Table XVI. Means of *Centropages typicus* observed with values of pH.

Centropages typicus was found in tows 2 and 3 in Bogue Sound (Table III); in numbers 15, 16, 18-22, 24-26, 38, and 39 in the ocean (Table VII, Fig. 11); none occurred in the Pamlico Sound material. Except for the last two tows outside (38 and 39), all occurrences of *C. typicus* fall within the ranges found at Beaufort Inlet with respect to season. Tows 38 and 39 from the *Albatross III* material were made at the edge of and in the tongue of cold water lying just north of Cape Hatteras (see "Hydrography") representing for this instance the southern limit of the coastwise counter current

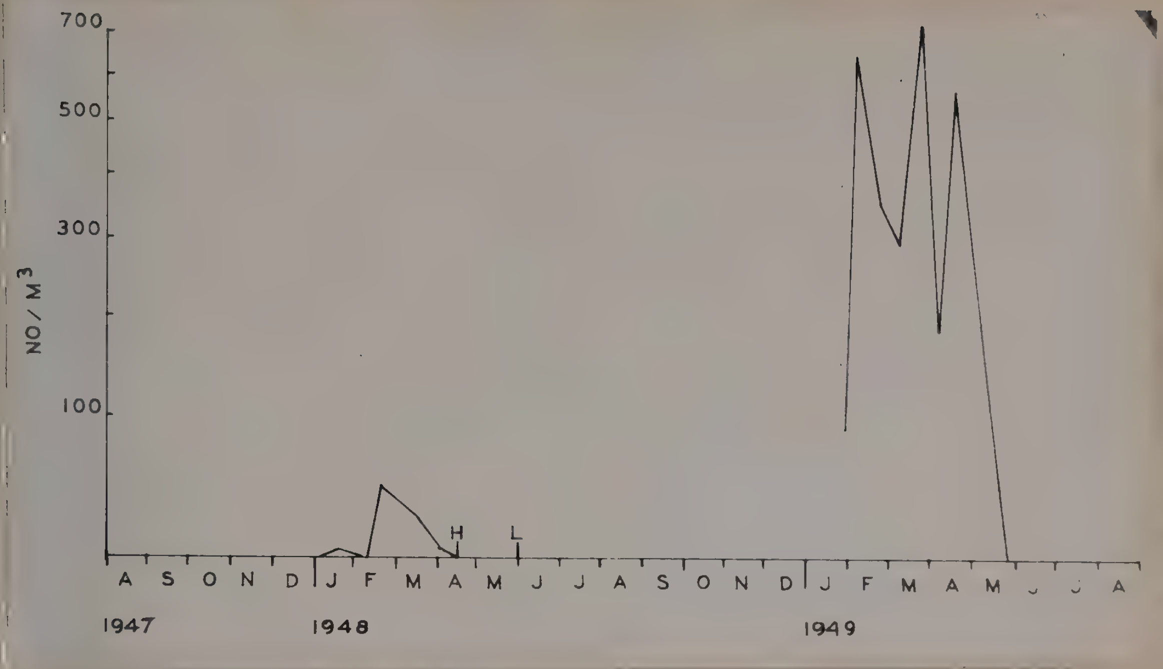


Figure 33. High and low tide means of *Centropages typicus*. Letters H and L refer to presence at high or low tide.

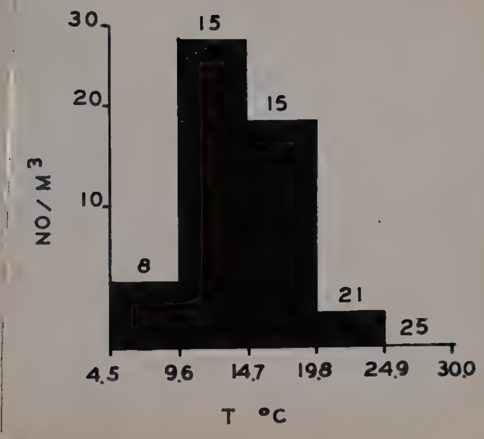


Figure 34. Means of *Centropages typicus* with ranges of temperature.

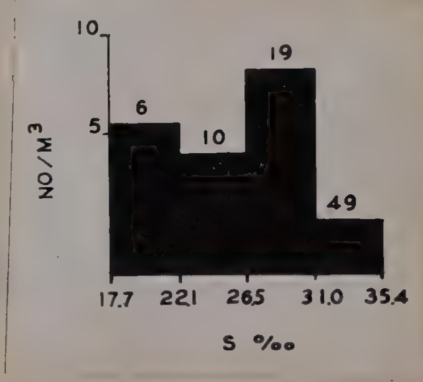


Figure 35. Means of *Centropages typicus* with ranges of salinity.

of the second cell in Figure 12.

Bigelow (1926) found *C. typicus* in greatest abundance in the late summer and fall in the Gulf of Maine, and Fish (1925) lists it as a common summer form at Woods Hole. Wilson (1932a) states that this was a common winter species in Chesapeake Bay. Reference to Figure 33 and 34 shows that *C. typicus* would be expected to occur at colder temperatures. Clarke (Galtsoff et al. 1937) found that *C. typicus* could not survive in water much above 20°C. No copepodid stages were found in summer. *Centropages typicus* may thus be regarded as a winter and spring form at Beaufort, and one of probable north temperate origin.

Clausocalanus furcatus (Brady). This small calanoid was found only twice in Beaufort Inlet: at high tides on November 4, 1948 and April 9, 1949. On November 4 it was found at a mean concentration of $17/m^3$. It was recorded only as present on April 9. The hydrographic conditions under which *C. furcatus* was found are shown in Table XVII.

Water Temp. °C	Salinity o/oo	Ext. Coef.	pH
19.2	33.5	0.84	8.1
15.5	32.4	1.51	8.1

Table XVII. Hydrographic conditions observed with occurrence of *Clausocalanus furcatus*.

In addition to the two occurrences at Beaufort Inlet,

Clausocalanus furcatus was found only in the ocean. Here it was found in tows 23, 25, 29, 30, 33, and 35-37 (Table VII, Fig. 11).

Cleve (1900) lists this species as a form common to the tropical Atlantic and it was certainly common in the tows taken in or near the Gulf Stream. Davis (unpublished data) has reported it from the Florida Keys and the Gulf of Mexico.

In view of the apparent tropical nature of this copepod, it was probably an inclusion in the Beaufort material as a result of the circulation from the Gulf Stream, as seen in Figure 12. Other occurrences of this nature will be noted later with different species. This copepod has not previously been reported from North Carolina.

Corycaeus amazonicus (F. Dahl). Figure 36 shows numbers of C. amazonicus encountered during the period of study. This species, as seen in Figures 37 and 38, occurred in greatest quantity at intermediate temperatures and at highest salinities. The high tide mean ($20/m^3$) was higher than that at low tide ($11/m^3$). Means occurring with values of pH are shown in Table XVIII.

Corycaeus amazonicus was not found in Bogue or Pamlico Sounds. In the ocean it was found in tows 28-31, 35, and 36 (Table VII, Fig. 11). It has been reported from the mouth of the Amazon, from Tortugas, and the Gulf of Mexico (Wilson 1949).

There is a possibility that this species may have been confused in some of the counts, with Corycaeus americanus

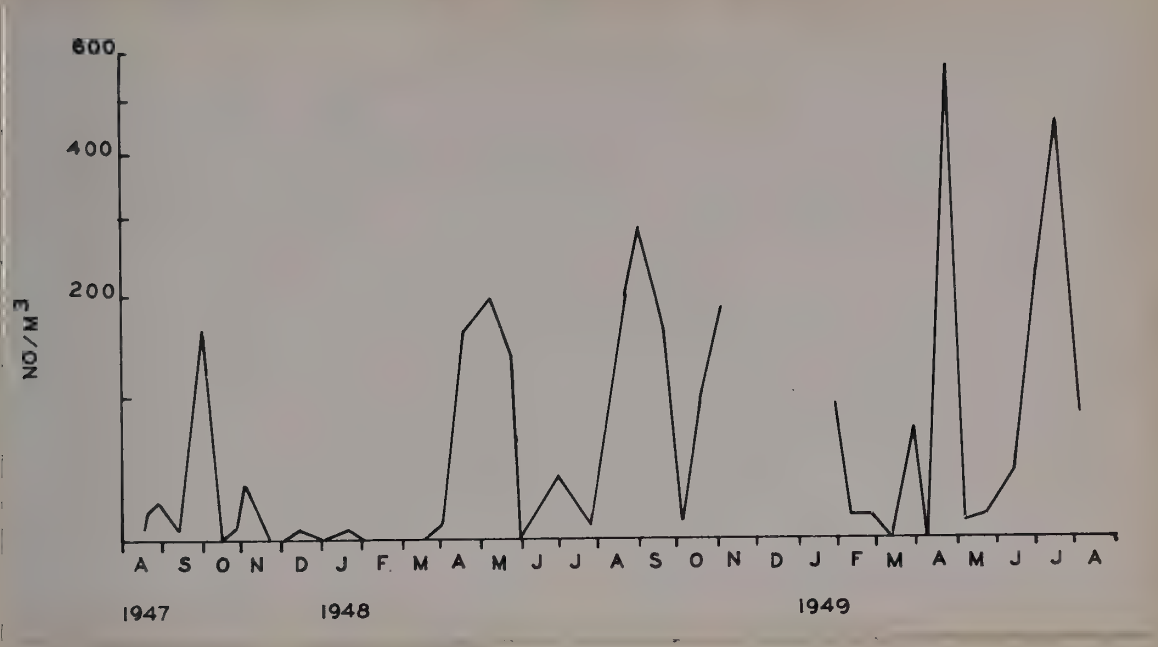


Figure 36. High and low tide means of *Corycaeus amazonicus*.

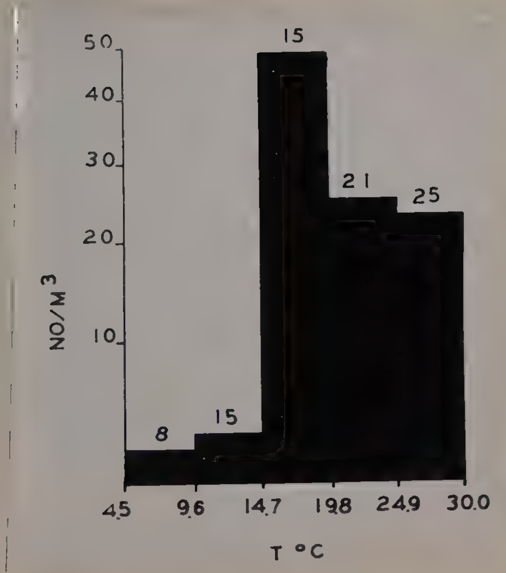


Figure 37. Means of *Corycaeus amazonicus* with temperature ranges.

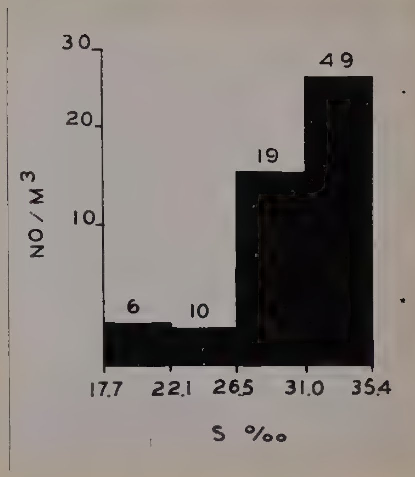


Figure 38. Means of *Corycaeus amazonicus* with ranges of salinity.

which it closely resembles. Corycaeus amazonicus has not previously been reported from North Carolina.

Means No/m^3	pH	Number Observations
0	<7.9	4
8.6	7.9	20
30	8.0	37
19	8.1	14
3.3	>8.1	4

Table XVIII. Means of Corycaeus amazonicus observed with values of pH.

Corycaeus americanus (M. Wilson). In Figure 39 may be seen the distribution of Corycaeus americanus during the period of study. It was found mostly at intermediate and higher temperatures (Fig. 40) and was most numerous at higher salinities (Fig. 41). Greater numbers were found at high tide (29/m^3) than at low tide (6.3/m^3). Table XIX gives means occurring with pH.

Means No/m^3	pH	Number Observations
0	<7.9	4
8.7	7.9	20
20	8.0	37
55	8.1	14
4.7	>8.1	4

Table XIX. Means of Corycaeus americanus observed with values of pH.

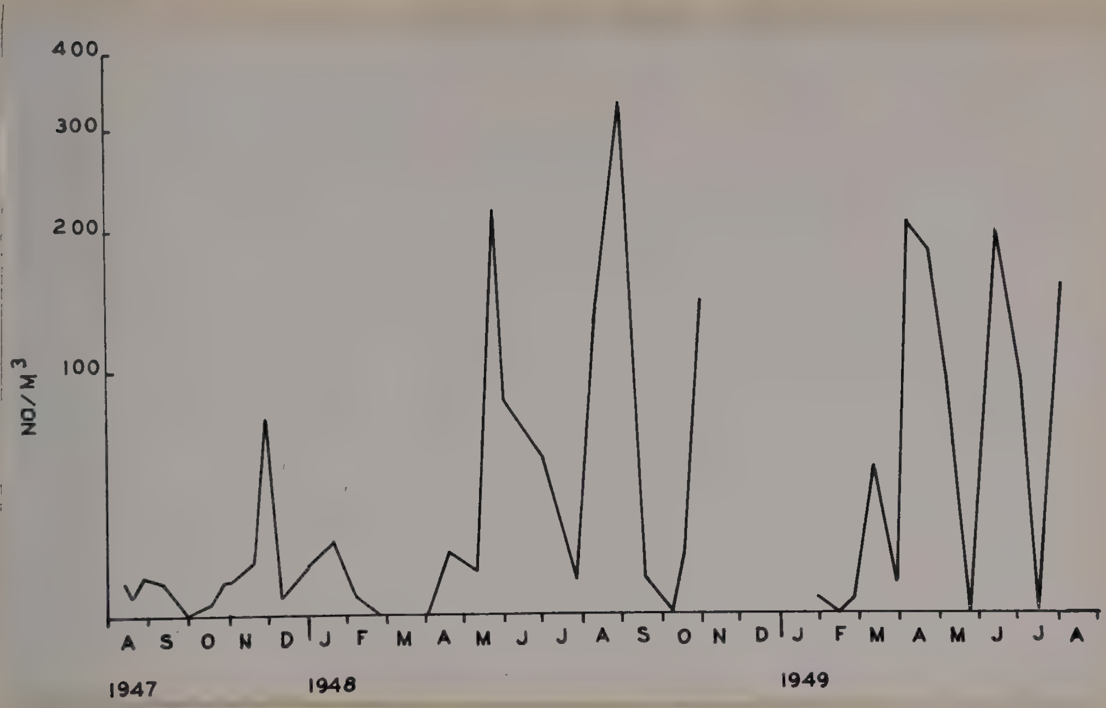


Figure 39. High and low tide means of *Corycaeus americanus.*

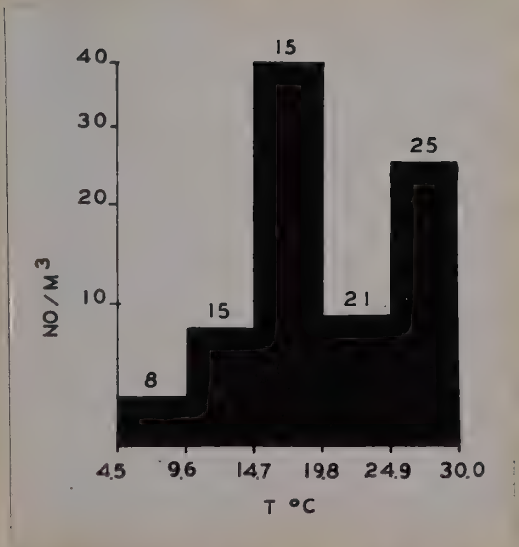


Figure 40. Means of *Corycaeus americanus* with ranges of temperature.

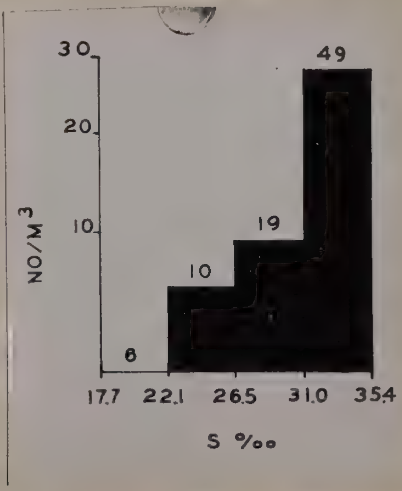


Figure 41. Means of *Corycaeus americanus* with ranges of salinity.

This species was more widely distributed than *C. amazonicus* in the areas investigated around Beaufort Inlet. It was found in tows 4, 5, and 9 (Table III) in Bogue Sound, but not in Pamlico Sound. Outside it occurred in tows 15, 22, 25, 26, 28-32, 35, 36, 38, and 39 (Table VII, Fig. 11). It is to be noted that this species was found in the cold water north of Cape Hatteras along with other species which typically occur at Woods Hole.

Because this species has been so recently described (Wilson 1949), relatively little is known of its distribution. It has been reported from Chesapeake Bay and the Gulf of Mexico (Wilson 1949).

Eucalanus pileatus Giesbrecht and *Eucalanus subcrassus* Giesbrecht. These two species (called *E. monachus* by Sutcliffe 1948) are thought to be referable to a single species. (W. Vervoort, private communication), and will be treated as such in this report. The morphological differences are relatively slight, and the present study could not show significant differences with respect to all ecological factors. Specimens belonging to one "species" or the other were seldom found together in a single tow; they were, however, almost completely intermixed with regard to time of year, temperature classes, and other factors, except salinity.

Eucalanus was most numerous in late summer and fall although it was recorded as being present at several scattered intervals throughout the year (Fig. 42). The group was found most frequently at high temperatures (Fig. 43). With respect

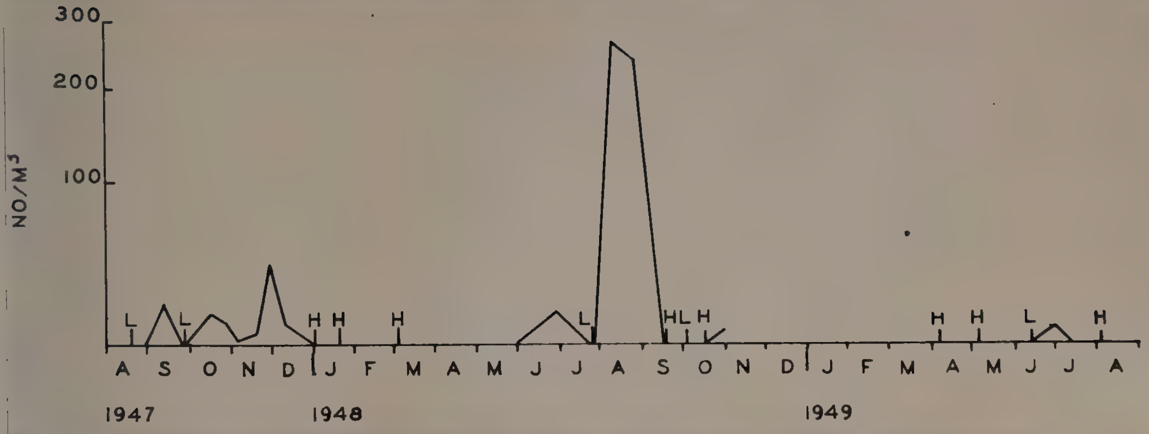


Figure 42. High and low tides means of Eucalanus subcrassus and E. pileatus. Letters H and L refer to presence at high or low tide.

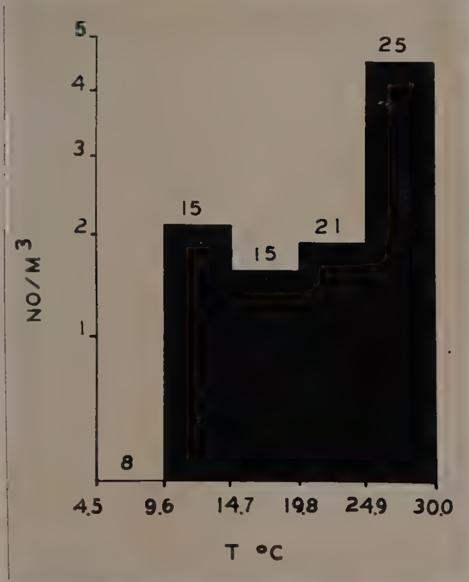


Figure 43. Means of Eucalanus subcrassus and E. pileatus with ranges of temperature.

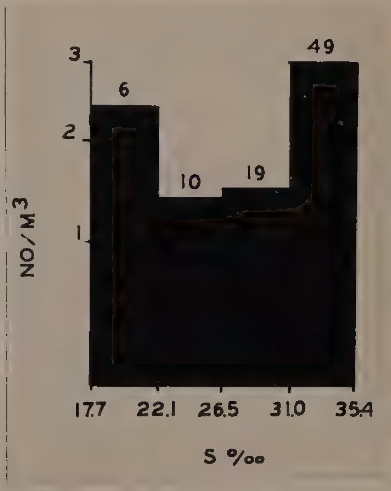


Figure 44. Means of Eucalanus subcrassus and E. pileatus with ranges of salinity.

to salinity, it will be noticed that in Figure 44 the graph has two well defined peaks at the extremes of the range. It was found that, while specimens of the E. pileatus type were relatively well represented in nearly all salinity classes, those of E. subcrassus were absent in the two lowest classes, and were numerous in the highest class. This is evidently the cause of the bimodal appearance of the graph. Eucalanus was found more frequently at high tide ($3.0/m^3$) than at low tide ($1.8/m^3$). Means of Eucalanus and pH are shown in Table XX.

Means No/m^3	pH	Number Observations
0	<7.9	4
2.1	7.9	20
2.6	8.0	37
2.8	8.1	14
0	>8.1	4

Table XX. Means of Eucalanus pileatus and E. subcrassus observed with values of pH.

Neither Eucalanus pileatus nor E. subcrassus were found in Bogue or Pamlico Sounds. In the ocean they were present in tows 31-37, and 39 (Table VII, Fig. 11). Cleve (1900) has recorded E. subcrassus in the tropical Atlantic and Davis (unpublished data) has listed it as occurring in the Gulf Stream off the Florida Keys and in the Gulf of Mexico. Most of the cold weather inclusions in Beaufort plankton probably represent, as with Clausocalanus furcatus, stragglers brought

in from the Gulf Stream.

Euterpina acutifrons (Dana). *Euterpina acutifrons* was found to be present during most of the year (Fig. 45), but as shown in Figure 46 was present in greatest numbers at higher temperatures. It was also most numerous at high salinities (Fig. 47). The mean concentration at high tide (96/m^3) was greater than that at low tide (48/m^3). Means calculated at values of pH are given in Table XXI.

Means No/m^3	pH	Number Observations
2.5	$<$7.9	4
37	7.9	20
106	8.0	37
164	8.1	14
103	$>$8.1	4

Table XXI. Means of *Euterpina acutifrons* observed with values of pH.

Euterpina acutifrons was found in tows 1,2,4, and 6-8 (Table III) from Bogue Sound and numbers 27-29, and 31 (Table VII, Fig. 11) outside. It was absent from Pamlico Sound possibly because of the low salinities encountered there.

This copepod has a wide distribution, according to Cleve (1900) who lists it as occurring in the southern North Sea, Newfoundland Banks, and the Rio Negro. Davis(unpublished data) has reported it from the Gulf Stream off Miami and the Gulf of Mexico. Dahl (1894) found it near the mouth of the Amazon.

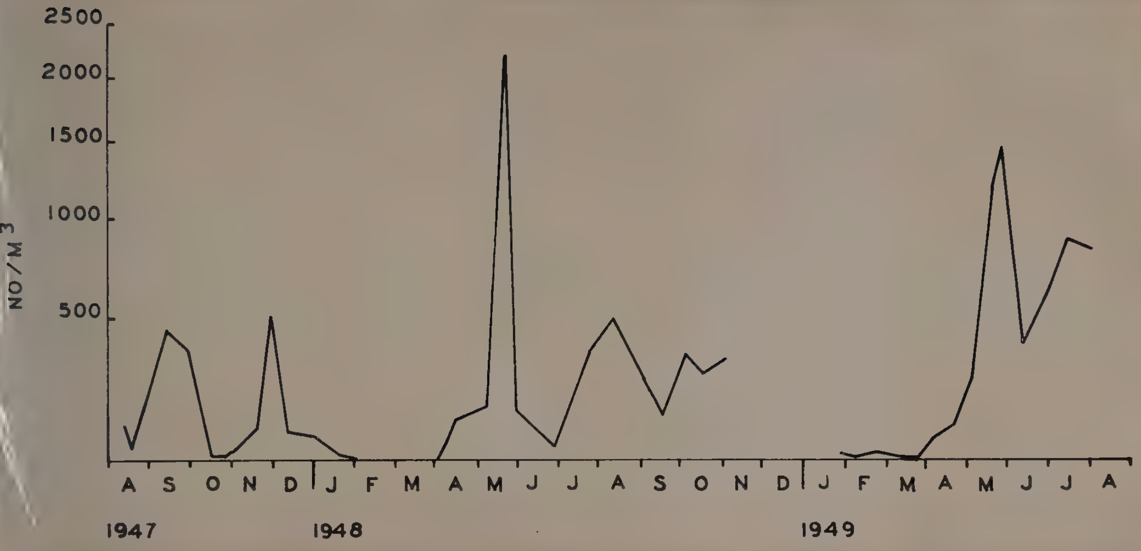


Figure 45. High and low tide means of Euterpina acutifrons.

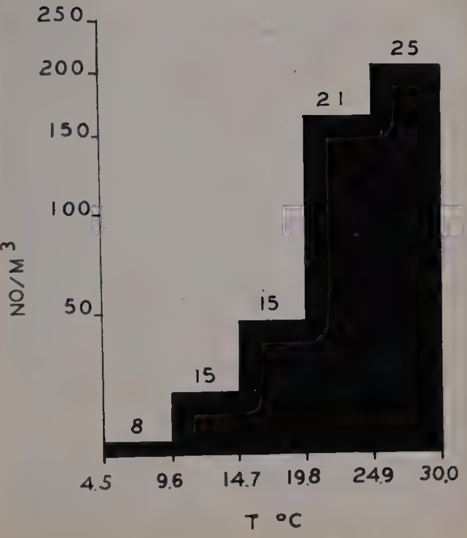


Figure 46. Means of Euterpina acutifrons with ranges of temperature.

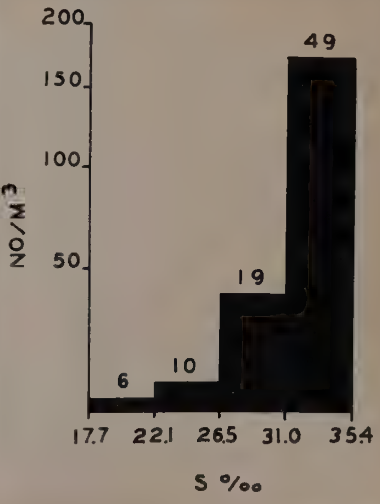


Figure 46. Means of Euterpina acutifrons with ranges of salinity.

Despite records from northern localities, _E_. _acutifrons_ was found in greatest numbers in the high temperature and salinity ranges (Figs. 46 and 47) at Beaufort very similar to those of tropical species, and will here be so considered. This species has not previously been reported from North Carolina.

Hemicyclops (?) _sp_. This copepod was found to be similar to the genus Saphirella Scott as described by Sewell (1924). However, Nicholls (1944) has presented reasons for ascribing this form to the genus Hemicyclops (benthic) as a developmental stage. It is not known at present whether or not the Beaufort specimens constitute a single species.

The distribution over the period of observation is shown in Figure 48. As may be seen in Figure 49, occurrences with respect to temperature are somewhat inconclusive. Greatest numbers were found to occur in the 22.1-26.4o/oo range of salinity (Fig. 50). The low tide mean ($9.5/m^3$) was found to be higher than that of high tide ($8.6/m^3$). Means coexistent with pH are given in Table XXII.

Means No/m^3	pH	Number Observations
16	<7.9	4
6.2	7.9	20
14	8.0	37
4.5	8.1	14
12	>8.1	4

Table XXII. Means of _Hemicyclops_ (?) _sp_. observed with values of pH.

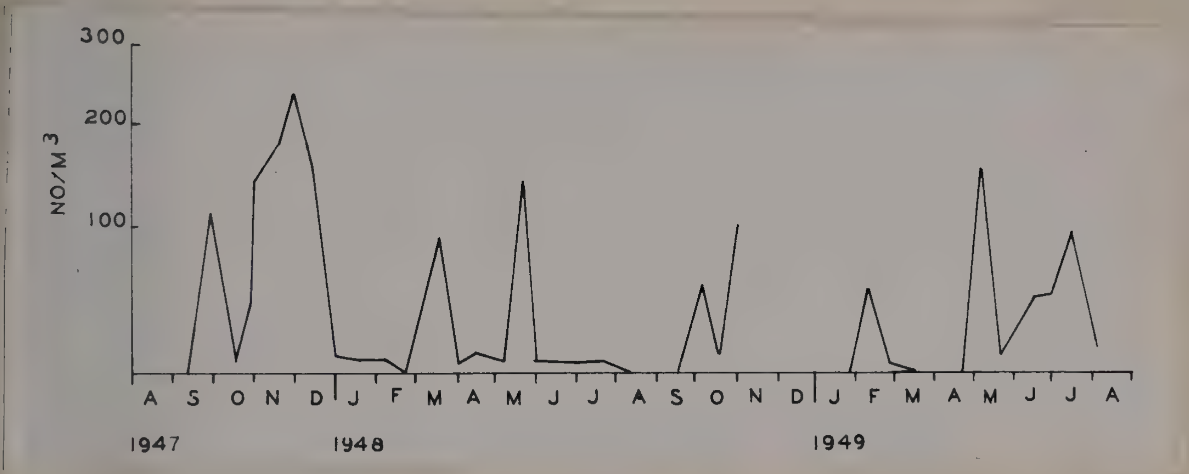


Figure 48. High and low tide means of *Hemicyclops* (?) *sp.*

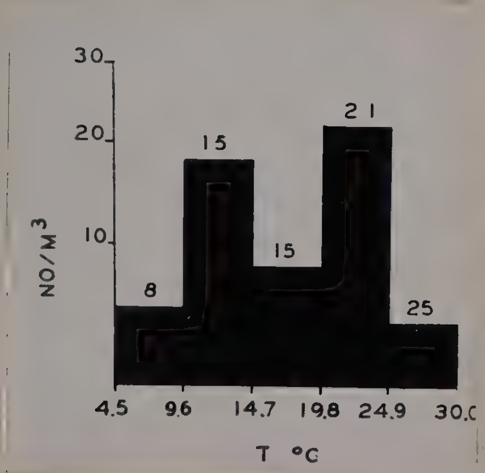


Figure 49. Means of *Hemicylops* (?) *sp.* with temperature ranges.

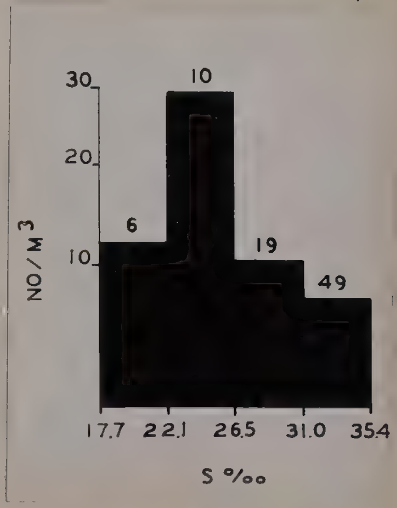


Figure 50. Means of *Hemicylops* (?) *sp.* with ranges of salinity.

Labidocera aestiva Wheeler. As may be seen from Figure 51, this is primarily a summer-fall species and was only occasionally found in Beaufort Inlet. None were found in 1949. Figures 52 and 53 show the number of occurrences (not the means) of *L. aestiva* in the temperature and salinity classes. Occurrences were more frequent at high temperatures and high salinities. The species occurred more frequently at high tides (5 times) than at low tides(3 times). Frequencies and values of pH are shown in Table XXIII.

No. of Occurrences	pH	Number Observations
0	<7.9	4
3	7.9	20
2	8.0	37
1	8.1	14
0	>8.1	4

Table XXIII. Frequencies of occurrence of *Labidocera aestiva* observed with values of pH.

Labidocera was not found in Bogue Sound, Pamlico Sound, or in the ocean. According to Fish (1925) and Wilson (1932) this is a relatively common summer copepod in the Woods Hole area. Wilson (1932a) found *L. aestiva* as a fall and winter species in Chesapeake Bay. From this geographical distribution it might seem that this species would be a winter form at Beaufort; however, as seen in Figures 51 and 52 this does not seem to be the case. The fact that Davis (unpublished data)

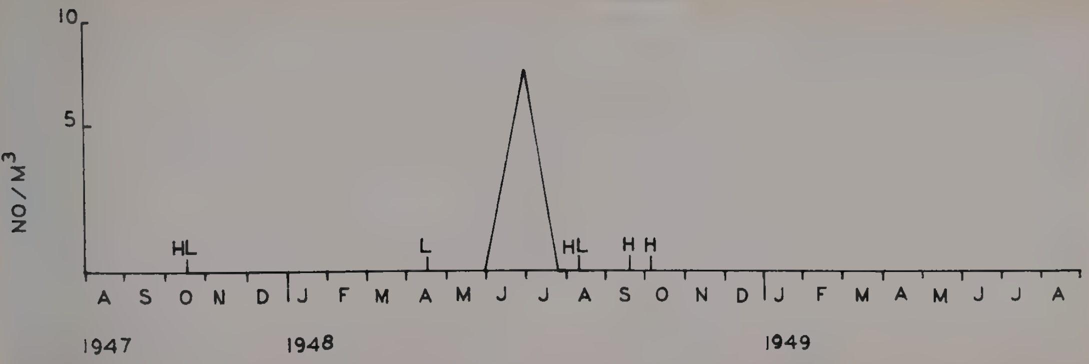


Figure 51. High and low tide means of *Labidocera aestiva*. Letters H and L refer to presence at high or low tide.

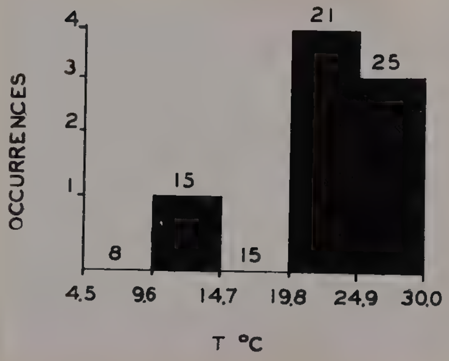


Figure 52. Occurrence of *Labidocera aestiva* with ranges of temperature.

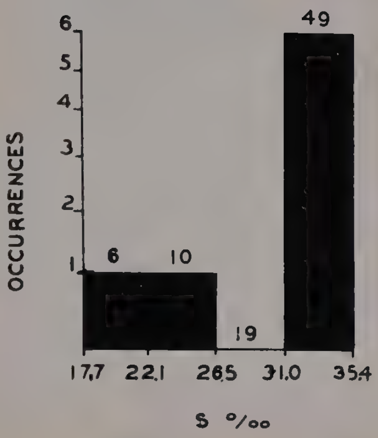


Figure 53. Occurrence of *Labidocera aestiva* with ranges of salinity.

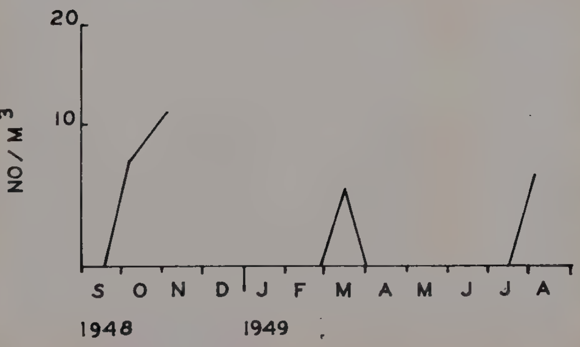


Figure 54. High and low tide means of *Microsetella norvegica*.

has several records of *L. aestiva* from the Gulf of Mexico together with the Beaufort observations raise the possibility of the existence of two physiological races.

Microsetella norvegica(Boeck). This harpacticoid was found only four times, in the fall of 1948 and the spring and summer of 1949. (Fig. 54). The hydrographic conditions under which it occurred are shown in Table XXIV.

Water Temp. °C	Salinity o/oo	pH	Ext. Coef.	Tide Stage
21.5	30.1	8.2	1.92	L
19.2	33.5	8.1	0.84	H
11.4	29.3	7.9	1.14	L
28.5	34.8	8.0	0.58	H

Table XXIV. Hydrographic conditions occurring with *Microsetella norvegica*.

Microsetella norvegica was not found in Bogue or Pamlico Sounds but was present in tows 23, 25, and 29 (Table VII, Fig. 11) taken in the ocean. Cleve (1900) reported this copepod (as *M. atlantica*) to be the most widely distributed in the Atlantic. It occurs from the tropical Atlantic to Greenland. Wilson (1932) has recorded it from Woods Hole and from Chesapeake Bay in winter (1932a). This copepod has not been previously reported from North Carolina.

Nannocalanus minor(Claus). *Nannocalanus minor* was found in Beaufort Inlet only three times during the investigation,

and was then only recorded as present. The hydrographic conditions under which it was found are given in Table XXV.

Date	Water Temp. °C	Salinity o/oo	Ext. Coef.	pH	Tide Stage
Nov.2,1947	21.7	32.5	1.50	8.0	H
Apr.3,1948	16.7	30.8	1.16	8.0	H
Jan.29,1949	14.7	27.8	0.90	8.0	L

Table XXV. Hydrographic conditions occurring with _Nannocalanus_ _minor_.

This species was not found in Bogue or Pamlico Sounds. Outside it was found in tows 33, 34, 36, 37, and 39 (Table VII, Fig. 11). Wilson (1932) reports that this species (as _Calanus_ _minor_) occurs in the Gulf Stream offshore from Woods Hole. Davis (unpublished data) has found it (as _Calanus_ _minor_) in the Gulf Stream off south Florida, and Cleve (1900) states that it (as _Calanus_ _minor_) is widespread in the tropical Atlantic. This species is probably a tropical one.

Oithona _brevicornis_ Giesbrecht and _Oithona_ _nana_ Giesbrecht. In the first year of this investigation it was not realized that both _Oithona_ _brevicornis_ and _O._ _nana_ were present. Therefore, these two species were not separated ecologically in this study. The similarity of the species made gross counts nearly impossible without individual examination of the specimens. Individuals were identified at intervals to gain some idea as to the distribution of these two species with respect to time.

While this gave no indication as to exactly when one species appeared and the other disappeared in the plankton, or as to the numerical proportions of the two species, it did indicate that *O. nana* was more prevalent in winter and spring while *O. brevicornis* was more numerous in summer and fall. Figure 55 shows that the combination was greatest in number during the warmer months (*O. brevicornis*?). In Figures 56 and 57 it may be seen that these species occurred most frequently at high temperatures and high salinities. The mean concentration of the species was greater at high tide ($1388/m^3$) than at low tide ($641/m^3$). Mean populations and pH are given in Table XXVI.

Means No/m^3	pH	Number Observations
116	<7.9	4
909	7.9	20
1211	8.0	37
1769	8.1	14
116	>8.1	4

Table XXVI. Means of *Oithona brevicornis* and *O. nana* observed with values of pH.

Oithona brevicornis or *O. nana* were found in tow numbers 2, and 6-9 in Bogue Sound (Table III) and in 12-14 in Pamlico Sound (Table VI, Fig. 11). Occurrences in the ocean were in tows 15, 16, 24, 25, and 27-32.

Oithona brevicornis has occurred at Woods Hole according to Fish (1925) who found it from June to November. He considers it a common summer copepod in that region. Wilson

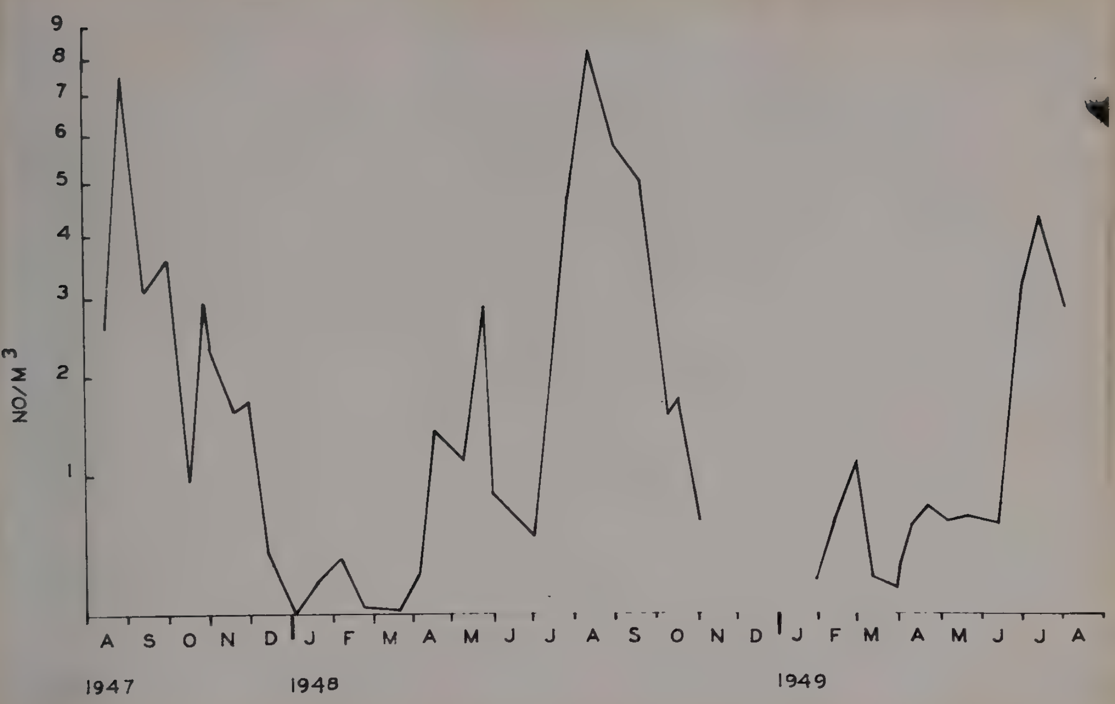
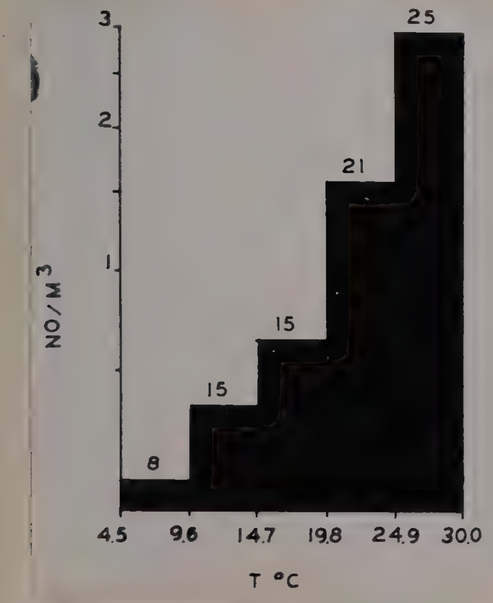


Figure 55. High and low tide means of *Oithona brevicornis* and *O. nana*. No/m^3 in thousands.



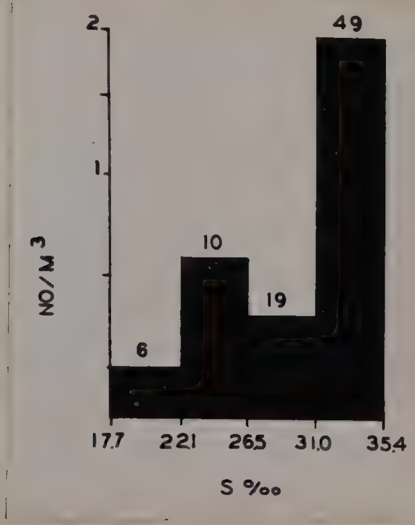


Figure 56. Means of *Oithona brevicornis* and *O. nana* with ranges of temperature. No/m^3 in thousands.

Figure.57. Means of *Oithona brevicornis* and *O. nana* with ranges of salinity. No/m^3 in thousands.

(1932a) has reported it from Chesapeake Bay in both summer and winter. This species has also been found in the tropical Atlantic (Wilson 1932). *Oithona nana* was found near Iceland and occurred in the tropical Atlantic (Wilson 1942). It also occurs in the Gulf of Mexico (Illg, private communication; Davis unpublished data) and off the east coast of Florida (Davis unpublished data). Because these two species were not separated in this account, no conclusions can be drawn. Neither has been previously reported from North Carolina.

Oithona plumifera Baird. *Oithona plumifera* was found only in summer and fall of 1947 and spring of 1949 (Fig. 58). Figures 59 and 60 show number of occurrences with temperature and salinity. This species occurred more frequently at high tide (6 times) than at low tide (2 times). Number of occurrences with pH are given in Table XXVII.

No. of Occurrences	pH	Number Observations
0	<7.9	4
1	7.9	20
1	8.0	37
5	8.1	14
0	>8.1	4

Table XXVII. Numbers of occurrences of *Oithona plumifera* observed with values of pH.

Oithona plumifera was not found in Bogue or Pamlico Sounds. In the ocean *O. plumifera* occurred in tows 33, 34, and 37

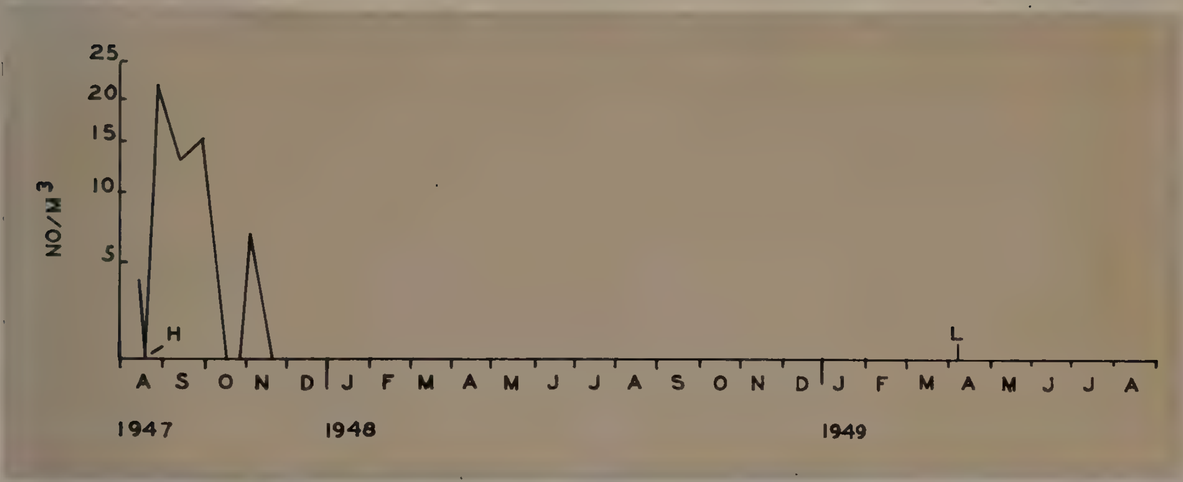


Figure 58. Means (high and low tide) of Oithona plumifera. Letters H and L refer to presence at high or low tide.

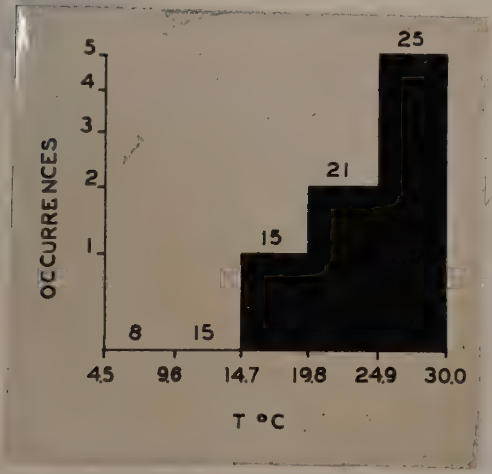


Figure 59. Occurrence of Oithona plumifera with ranges of temperature.

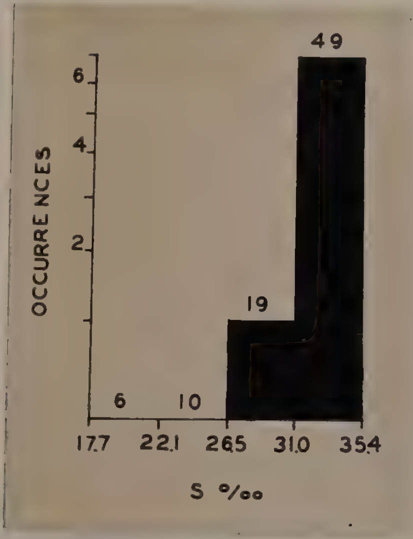


Figure 60. Occurrence of Oithona plumifera with ranges of salinity.

(Table VII, Fig. 11). Although this species has been found as far north as Iceland (Wilson 1942), it has been most commonly encountered much nearer the equator and it is thought by Cleve (1900) and Wilson (1932) to be a tropical species. Davis (unpublished data) has found this species in the Gulf of Mexico and in the Gulf Stream off south Florida.

The fact that *O. plumifera* was most frequently found at higher temperatures at Beaufort (Fig. 59) would support the idea that this species is a tropical one. *O. plumifera* has not previously been reported from North Carolina.

Oithona similis Claus. This cyclopoid was found primarily in winter and spring (Fig. 61). Figures 62 and 63 show that it was more prevalent at intermediate temperatures and salinities. Slightly more were found at high tide ($4.0/m^3$) than at low tide ($3.8/m^3$). Means with values of pH are given in Table XXVIII.

Means No/m^3	pH	Number Observations
0	<7.9	4
4.4	7.9	20
4.8	8.0	37
5.2	8.1	14
5	>8.1	4

Table XXVIII. Means of *Oithona similis* observed with values of pH.

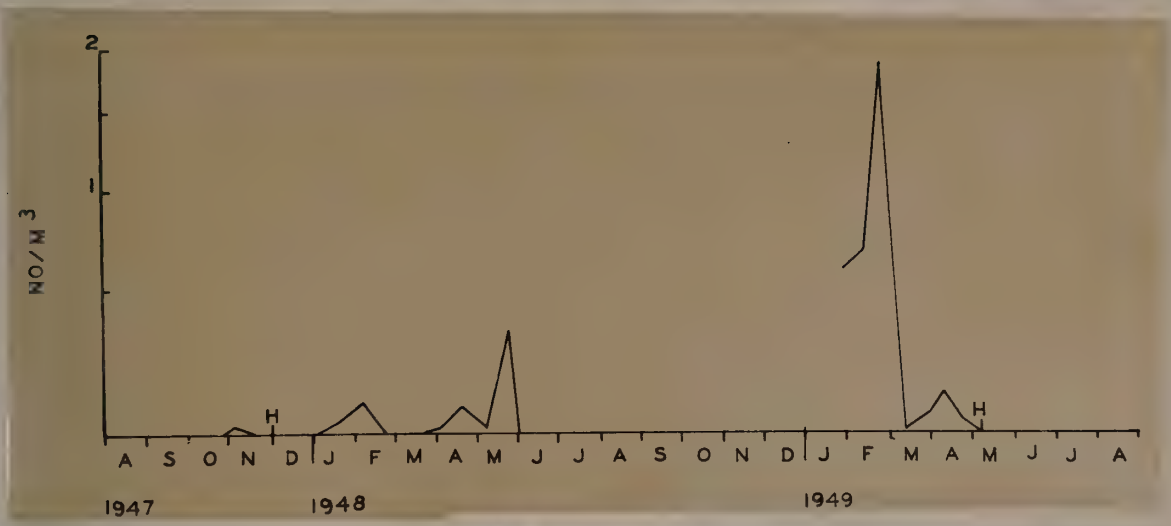


Figure 61. High and low tide means of Oithona similis. Letters H and L refer to presence at high or low tide. No/m^3 in thousands.

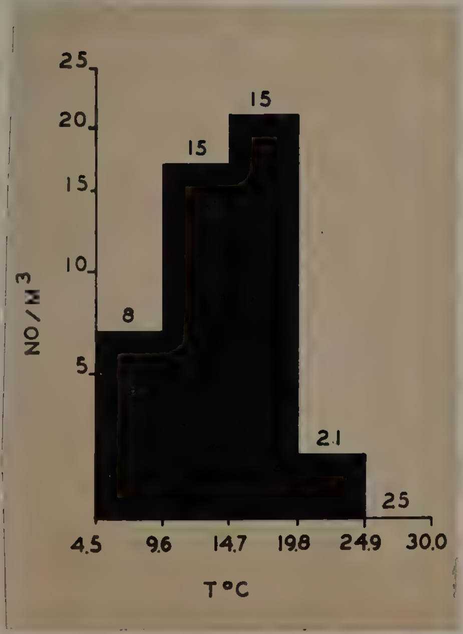


Figure 62. Means of Oithona similis with ranges of temperature.

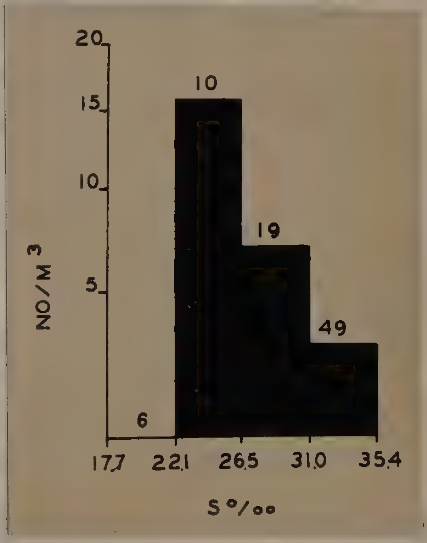


Figure 63. Means of Oithona similis with ranges of salinity.

Oithona similis was found twice in Bogue Sound in tows 3 and 6 (Table III) but not found in Pamlico Sound. Outside it was widely distributed where temperatures were relatively low. It occurred in tow numbers 16-22, 24, 26, 29-31, 38, and 39 (Table VII, Fig. 11).

Fish (1925) lists this copepod as a summer form at Woods Hole and Wilson(1932a) found it mostly during fall and winter in Chesapeake Bay. Cleve (1900) classes this species as one of the commonest copepods of the temperate regions.

The seasonal distribution (Fig. 61) and the temperature ranges of greatest abundance (Fig. 62) of *Oithona similis* seem to agree with the geographical occurrences found by other investigators. This form was found from points north of Cape Hatteras to Cape Fear during the colder weather and was found in the cold water just north of Cape Hatteras in May and June 1949. Judging from geographical distribution and the present observations at Beaufort, *Oithona similis* is probably of north temperate origin. This species has not previously been reported from North Carolina.

Oithona spinirostris Claus. It may be seen in Figure 64 that this species was present most frequently and in greatest number in summer and fall. Correlations with temperature and salinity show greatest numbers at highest temperatures and salinities (Figs. 65 and 66). Greater numbers were present at high tide ($2.4/m^3$) than at low tide ($1.1/m^3$). Means occurring with pH are given in Table XXIX.

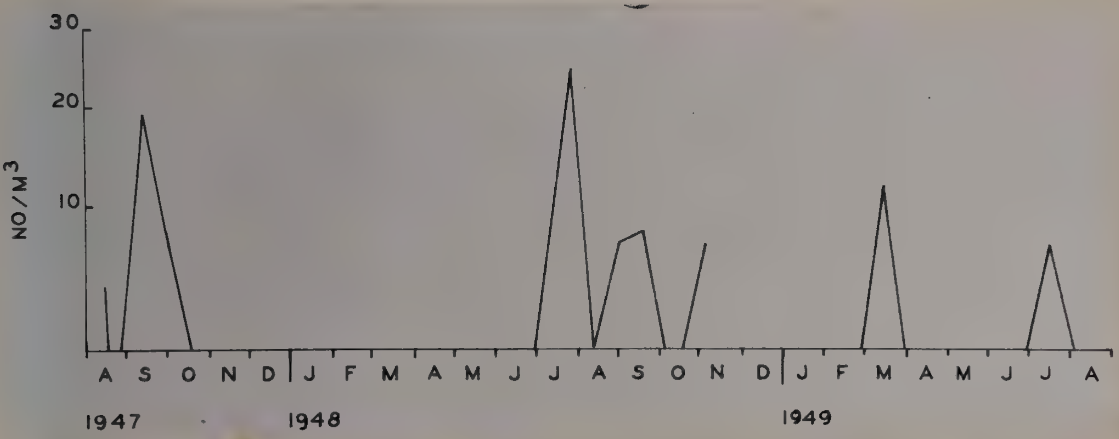


Figure 64. High and low tide means of *Oithona spinirostris*.

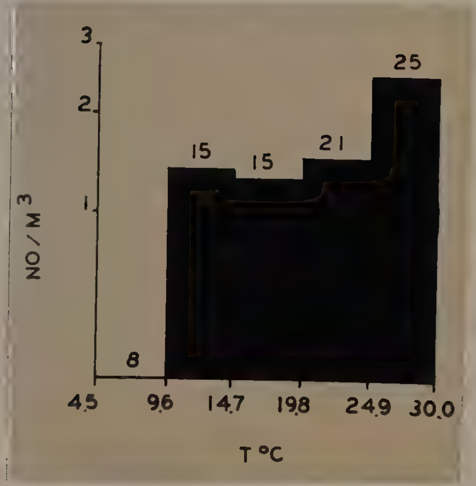


Figure 65. Means of *Oithona spinirostris* with ranges of temperature.

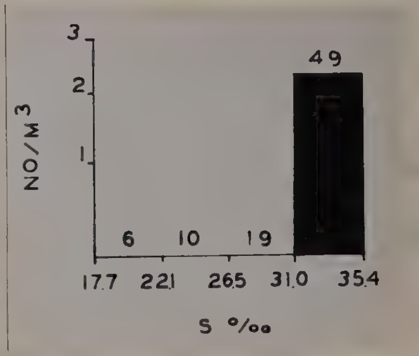


Figure 66. Means of *Oithona spnirostris* with ranges of salinity.

Means No/m^3	pH	Number Observations
0	<7.9	4
1.2	7.9	20
1.5	8.0	37
3.66	8.1	14
0	>8.1	4

Table XIX. Means of *Oithona spinirostris* observed with values of pH.

Oithona spinirostris was not found in Bogue or Pamlico Sounds. In the ocean it occurred in tows 31 and 36 (Table VII, Fig. 11). This copepod appears to be very widely distributed, for Wilson (1942) found it from points near Greenland to the Caribbean. He also found it in the entrance and outside of Chesapeake Bay in August and December (Wilson 1932a). This copepod was not previously reported from North Carolina.

Oncaea venusta Philippi. *Oncaea venusta* was found to be most numerous during the period of study during summer and fall as may be seen in Figure 67. Greatest numbers occurred in the 19.8-24.8°C range of temperature, and in the higher salinities (Fig. 68 and 69), although the latter is not so marked. Correlation with time of day showed somewhat greater numbers during late morning and around midday. *O. venusta* occurred more frequently at high tide (4.6/m^3) than at low tide (3.1/m^3). Means with pH are given in Table. XXX.

Oncaea venusta was found in tow 7 in Bogue Sound (Table III) but not im Pamlico Sound. In the ocean it occurred in

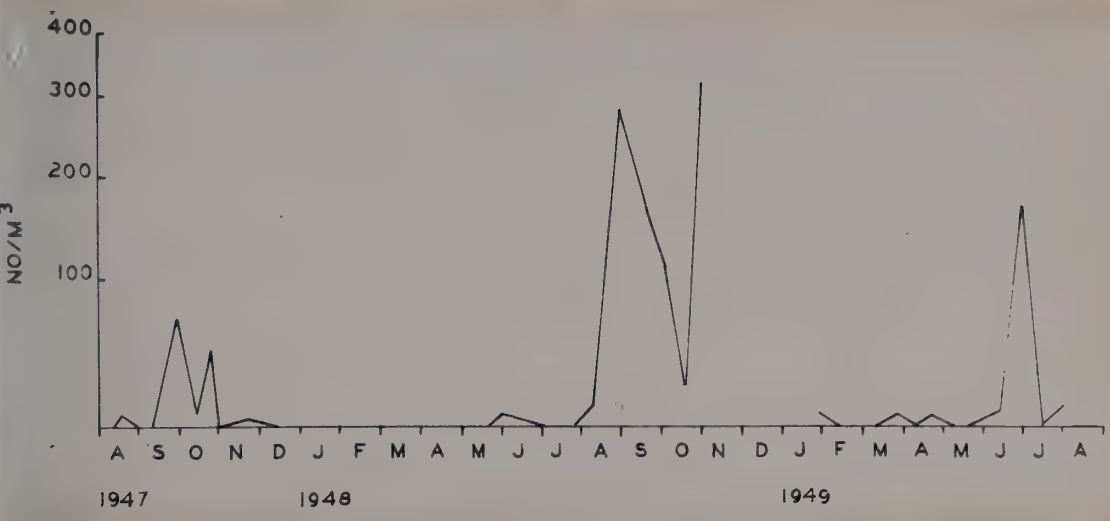


Figure 67. High and low tide means of Oncaea venusta.

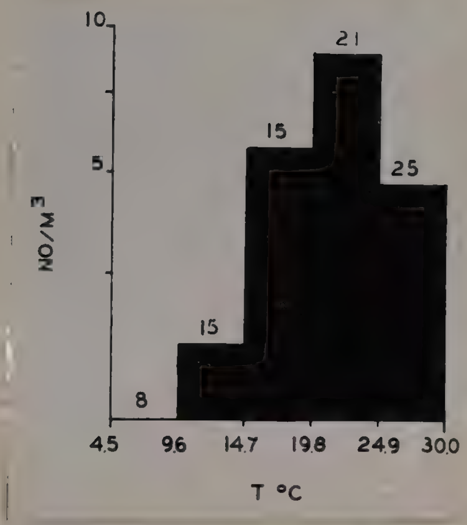


Figure 68. Means of Oncaea venusta with ranges of temperature.

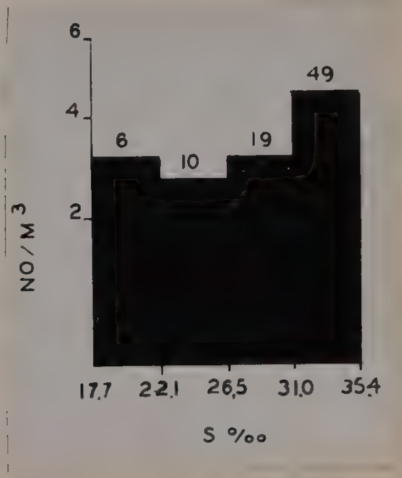


Figure 69. Means of Oncaea venusta with ranges of salinity.

samples 23, 25, 29, 33-35, and 39 (Table VII, Fig. 11).

Means No/m^3	pH	Number Observations
4.9	<7.9	4
2.3	7.9	20
3.2	8.0	37
7.0	8.1	14
2.7	>8.1	4

Table XXX. Means of _Oncaea_ _venusta_ observed with values of pH.

Wheeler (1899) found this species in the Gulf Stream off Martha's Vineyard in July, and Wilson (1932a) found it near the 100 fathom line out from Chesapeake Bay. He also reported it (1949) from near Iceland in June. Cleve (1900) indicates that this is a tropical species, but suggests that it might be temperate as well.

The distribution of Oncaea with respect to the temperature (Fig. 68) would suggest that it might be a southern temperate type. It is most likely distributed by the Gulf Stream. This species has not been previously reported from North Carolina.

Paracalanus _parvus_ (Claus): As may be seen in Figure 70 _Paracalanus_ _parvus_ was found in greatest numbers in summer and fall, although it was present nearly all year round. Correlations with temperature and salinity (Figs. 71 and 72) showed that it occurred most frequently at high temperatures

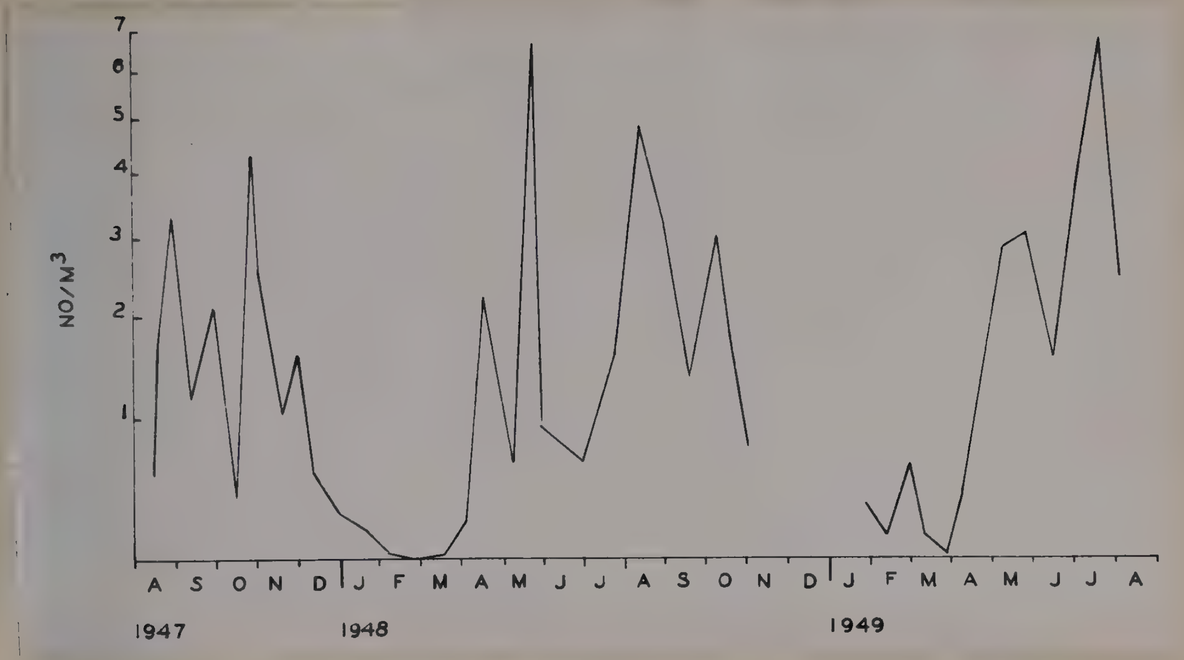
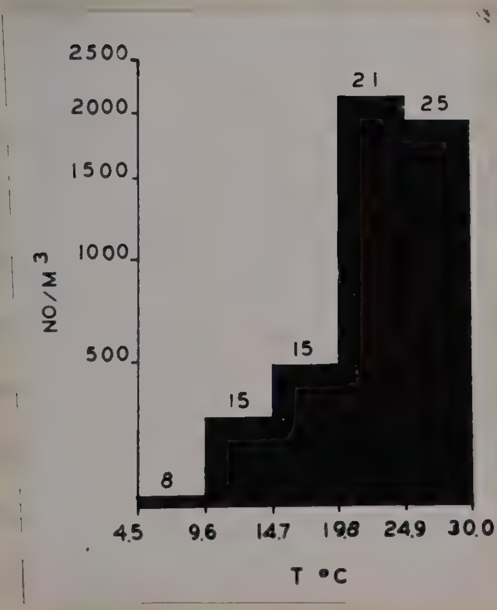


Figure 70. High and low tide means of Paracalanus parvus/ No/m^3 in thousands.



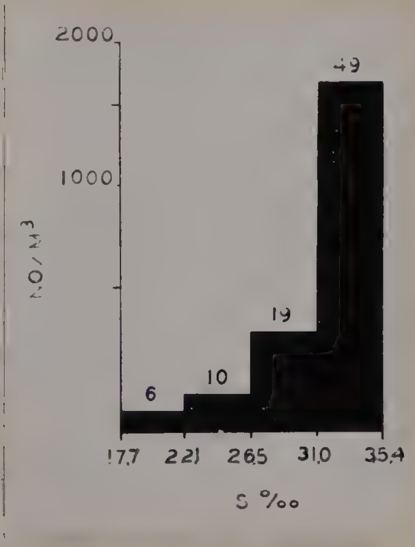


Figure 71. Means of Paracalanus parvus with ranges of temperature.

Figure 72. Means of Paracalanus parvus with ranges of salinity.

and salinities. It was present at high tide in much greater numbers (1247/m^3) than at low tide (409/m^3). Numbers with values of pH are given in Table XXXI.

Means No/m^3	pH	Number Observations
31	<7.9	4
413	7.9	20
1180	8.0	37
1534	8.1	14
72	>8.1	4

Table XXXI. Means of *Paracalanus parvus* observed with values of pH.

Paracalanus parvus was found in tow numbers 2, 3, and 6-9 (Table III) in Bogue Sound and numbers 12-14 (Table VI, Fig. 11) in Pamlico Sound. In the ocean it occurred in numbers 15, and 21-32 (Table VII, Fig. 11).

This species has been reported from the south Atlantic off the Cape of Good Hope to the north of Iceland (Bigelow 1926), and many points in between such as near Rio de Janeiro (Oliveira 1945), the Gulf of Mexico (Illg, private communication; Davis unpublished data), inland waters and the Gulf Stream off south Florida (Davis unpublished data), Chesapeake Bay (Wilson 1932a), Woods Hole (Fish 1925, Wilson 1932), Gulf Stream off Woods Hole (Wheeler 1899), and the Gulf of Maine (Bigelow 1926). Wilson (1932a) found that *P. parvus* was most numerous during fall and winter in Chesapeake Bay, and Bigelow found that it was most plentiful in summer and

and early fall in the Gulf of Maine but present nearly all year.

Wolfenden (1906) described two subspecies of *P. parvus*, a northern and a southern form. Although this subdivision has not been upheld by later authors, it has been pointed out that physiological races must exist in this ubiquitous species (Gurney 1927). Sewell (1948) has described races existing in a number of species of copepods. *Paracalanus parvus* at Beaufort, judging from the present evidence, is more frequent at warmer temperatures, which is apparently not the case in Chesapeake Bay. This might indicate local races for the Atlantic coast.

Pontella meadii Wheeler. *Pontella meadii* was found on June 30, 1948 at high and low tides at a mean concentration of 27/m^3. Hydrographic conditions on this date are given in Table XXXII.

Water Temp. °C	Salinity o/oo	Ext. Coef.	pH	Tide
28.5	34.2	0.94	7.9	H
29.4	34.0	0.57	7.9	L

Table XXXII. Hydrographic conditions observed with *Pontella meadii*.

Pontella meadii was found only in Beaufort Inlet. This occurrence, however, was in the summer, possibly indicating a non-northern origin. Wilson (1932a) says of this species: "Wheeler obtained only a few specimens in July and implied

that they had been blown in from the southeast during a storm. Fish also recorded it as a summer form from the Gulf stream. Its presence on the 100 fathom line at the latitude of Chesapeake Bay indicates that it is a southern form that occasionally gets as far north as Woods Hole. It has not thus far been found in the Gulf of Maine. It was found only in the outer portion of Chesapeake Bay during the summer."

Pseudodiaptomus coronatus Williams. It may be seen in Figure 73 that Pseudodiaptomus coronatus was found primarily during spring and fall during the time of observation. It was associated most frequently with temperatures of the 19.8-24.8°C range and with low salinities as may be seen in Figures 74 and 75. Slightly greater numbers were found at high tide ($3.4/m^3$) than at low tide ($3.1/m^3$). Means occurring with values of pH are given in Table XXXIII.

Means No/m³	pH	Number Observations
4.6	<7.9	4
1.8	7.9	20
3.7	8.0	37
2.1	8.1	14
11	>8.1	4

Table XXXIII. Means of Pseudodiaptomus coronatus observed with values of pH

Pseudodiaptomus coronatus occurred in tow number 9 (Table III) in Bogue Sound. It was not found in Pamlico Sound or in

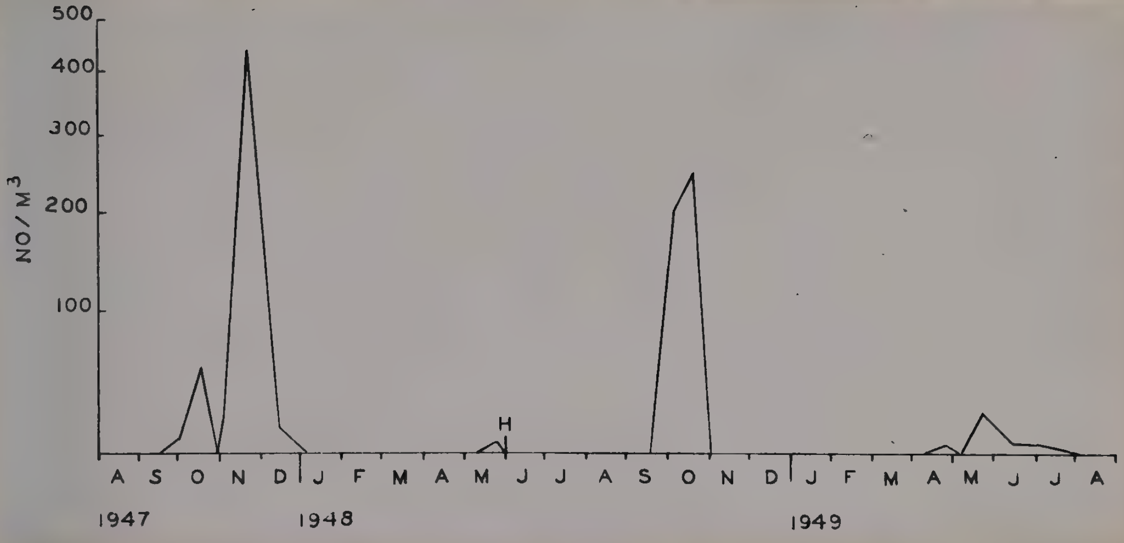


Figure 73. High and low tide means of *Pseudodiaptomus coronatus*. Letters H and L refer to presence at high or low tides.

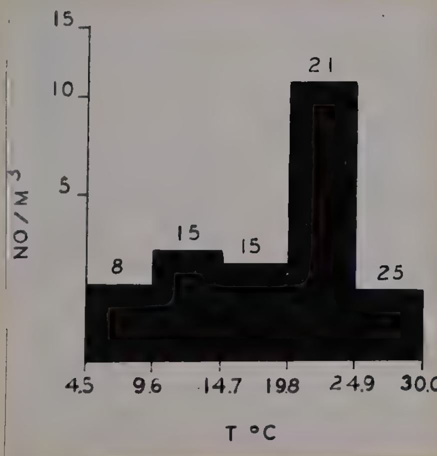


Figure 74. Means of *Pseudodiaptomus coronatus* with ranges of temperature.

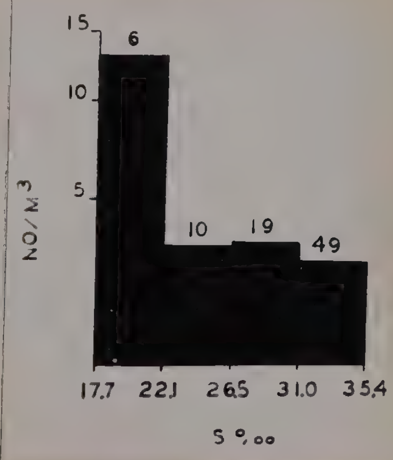


Figure 75. Means of *Pseudodiaptomus coronatus* with ranges of ~~temperature~~.
salinity

the ocean.

This is a fall species at Woods Hole (Fish 1925), and a fall and early winter form in Chesapeake Bay (Wilson 1932a). It has been reported from Long Lake in south Florida with a salinity of 15.39o/oo by Davis (1948) and from inland waters around southeast Florida by the same author (unpublished data). Illg (private communication) has found it in the Gulf of Mexico. Wilson (1932) found this species common in brackish water. P. coronatus was found actively breeding in the channel by the Duke Marine Laboratory all three summers of the investigation although it did not always occur in the tows in the Inlet. Males and females were found copulating, as well as females with egg sacs.

Temora stylifera (Dana). This species was recorded as present at high tide on November 4, 1948, and February 27, 1949. Hydrographic conditions are given in Table XXXIV.

Water Temp°C	Salinity o/oo	Ext. Coef.	pH
19.2	33.5	0.84	8.1
14.1	31.3	0.48	8.1

Table XXXIV. Hydrographic conditions observed with Temora stylifera/

In addition to the two occurrences at Beaufort, T. stylifera was found mainly in offshore stations where it was relatively common (tows 33,35-37, and 39; Table VII, Fig. 11).

Wilson has reported a few specimens from near Woods Hole. A single female was found southeast of Nova Scotia in September (Bigelow 1926). Davis (unpublished data) found this species in the Gulf Stream off south Florida and in the Gulf of Mexico, and Dahl (1894) reported it from near the mouth of the Amazon. Cleve (1900) lists several tropical Atlantic occurrences and classes this copepod as a tropical type.

Although found in late fall and winter at Beaufort, _T. stylifera_ is almost surely a tropical copepod. It was possibly pulled in from the Gulf Stream.

Temora turbinata (Dana). _Temora turbinata_ was found to be most numerous in summer and fall (Fig. 76). In Figures 77 and 78 it may be seen that it occurred more frequently at high temperatures and salinities. It apparently showed a correlation with time of day in that lower numbers were found around midday and higher numbers in early morning and late afternoon. It was more numerous at high tides ($8.6/m^3$) than at low tides ($6.3/m^3$). Populations coincident with values of pH are given in Table XXXV.

Temora turbinata was found in tow number 2 (Table III) in Bogue Sound and in tows 31-37, and 39 in the ocean (Table VII, Fig. 11). It was not found in Pamlico Sound.

Bigelow (1926) says that _T. turbinata_ is " a rare stray from the south" in the Gulf of Maine. Wilson (1932) makes a similar statement for the Woods Hole area but found it in "numbers sufficiently large to give it considerable economic importance" in Chesapeake Bay (1932a). It was most

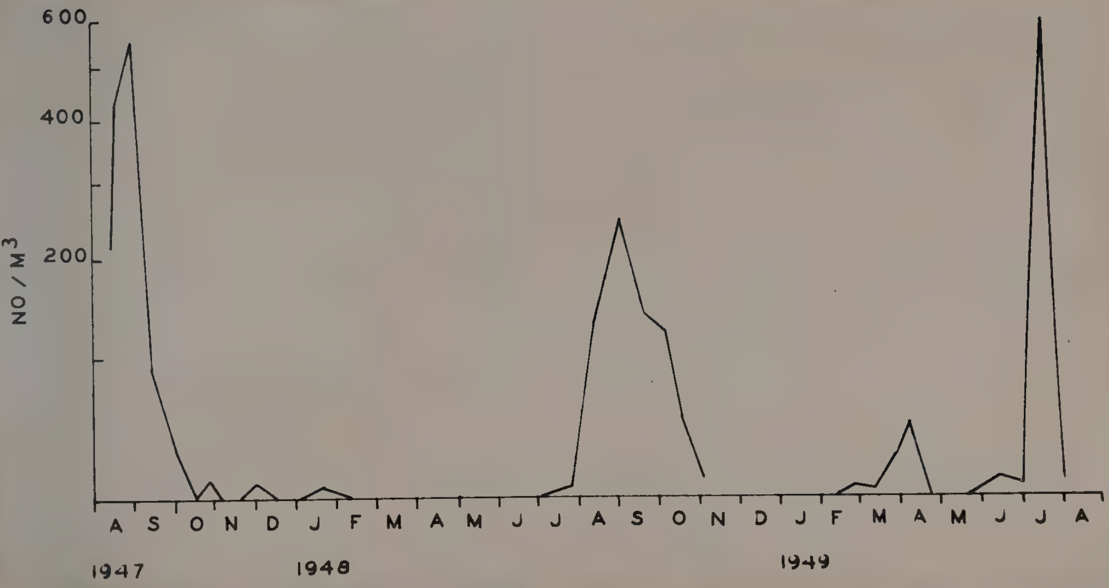


Figure 76. High and low tide means of *Temora turbinata*

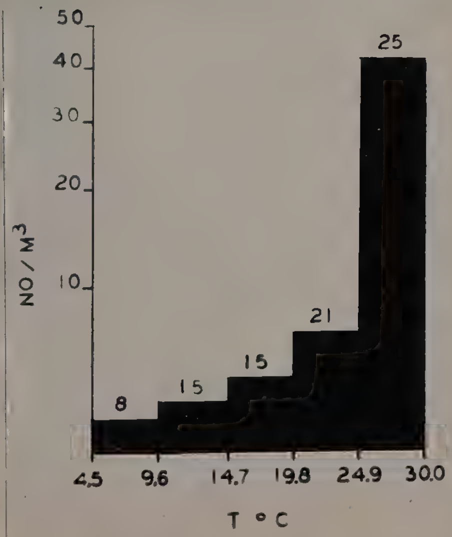


Figure 77. Means of *Temora turbinata* with ranges of temperature.

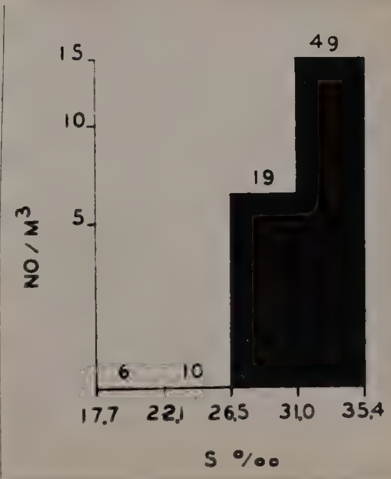


Figure 78. Means of *Temora turbinata* with ranges of salinity.

abundant there in autumn and winter.

Means No/m^3	pH	Number Observations
0	<7.9	4
11	7.9	20
3.6	8.0	37
53	8.1	14
2.7	>8.1	4

Table XXXV. Means of Temora turbinata observed with values of pH.

The findings at Beaufort differ from those of Wilson (1932a) for, unless a different race is possibly involved, Figures 76 and 77 show marked characteristics which one might attribute to a tropical species. Temora turbinata has been found by the author in the Florida Keys and in Biscayne Bay near Miami. Davis (unpublished data) has found it about southeast Florida and in the Gulf of Mexico. Illg(private communication) has also recorded T. turbinata from the latter locality. In view of the Beaufort findings and the occurrence of the species in and near the Gulf Stream, the T. turbinata that is found at Beaufort might be regarded as of tropical origin, if like other copepods of this type, it does not somehow survive the colder periods in some unrecognized form.

Copepod Nauplii

As may be seen in Figure 79, nauplii were generally more numerous in spring, summer, and fall during the period of

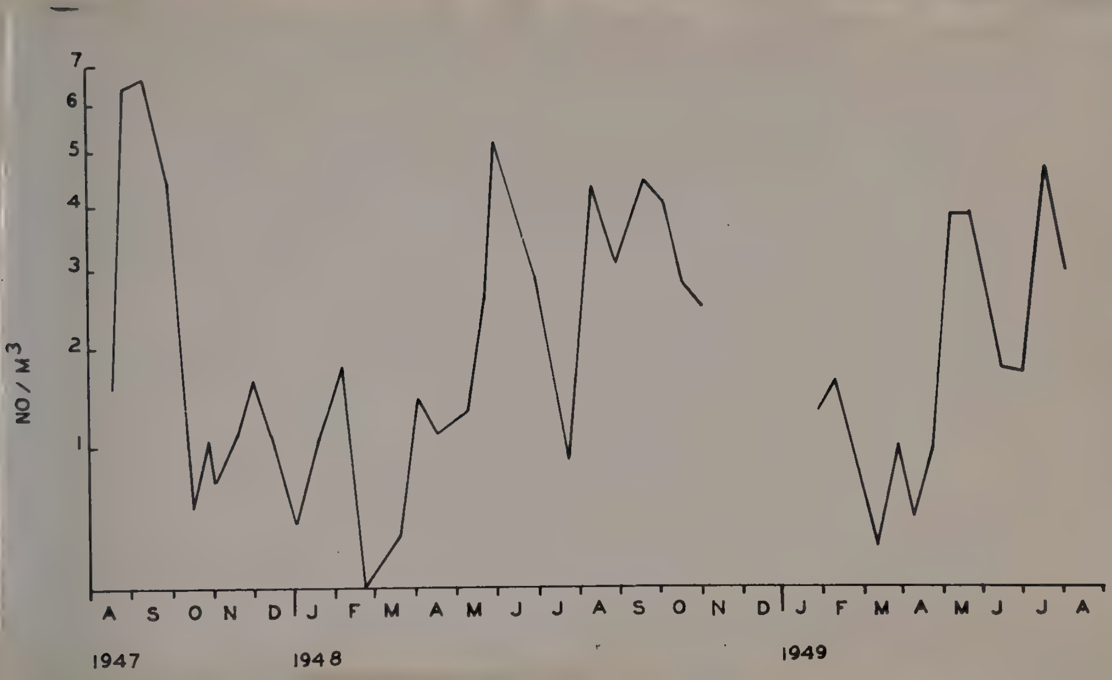


Figure 79. High and low tide means of copepod nauplii. No/m^3 in thousands.

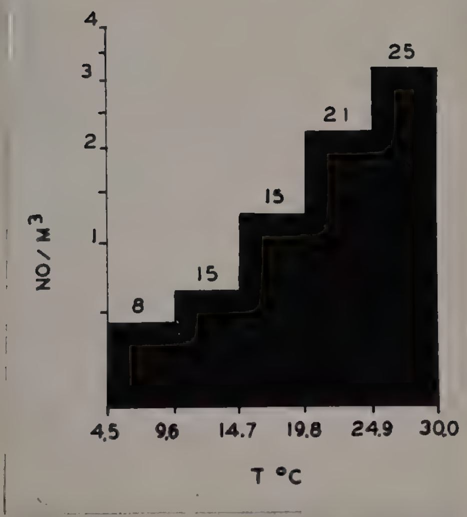


Figure 80. Means of copepod nauplii with ranges of temperature. No/m^3 in thousands.

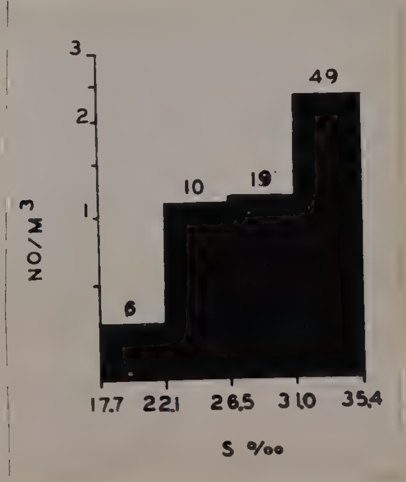


Figure 81. Means of copepod nauplii with ranges of salinity. No/m^3 in thousands.

observation than during the winter. They occurred most frequently at high temperatures and high salinities (Figs. 80 and 81). The mean concentration was higher at high tide (1841/m^3) than at low tide (1306/m^3). Numbers of nauplii and values of pH are given in Table XXXVI.

Means No/m^3	pH	Number Observations
128	<7.9	4
2090	7.9	20
1753	8.0	37
1941	8.1	14
1223	>8.1	4

Table XXXVI. Means of copepod nauplii observed with values of pH.

Pelecypod larvae

It may be seen in Figure 82 that this group was most numerous during the late spring, summer and fall of the period of observation. Greatest numbers were found at high

Means No/m^3	pH	Number Observations
3.6	<7.9	4
258	7.9	20
210	8.0	37
266	8.1	14
113	>8.1	4

Table XXXVII. Means of pelecypod larvae observed with values of pH.

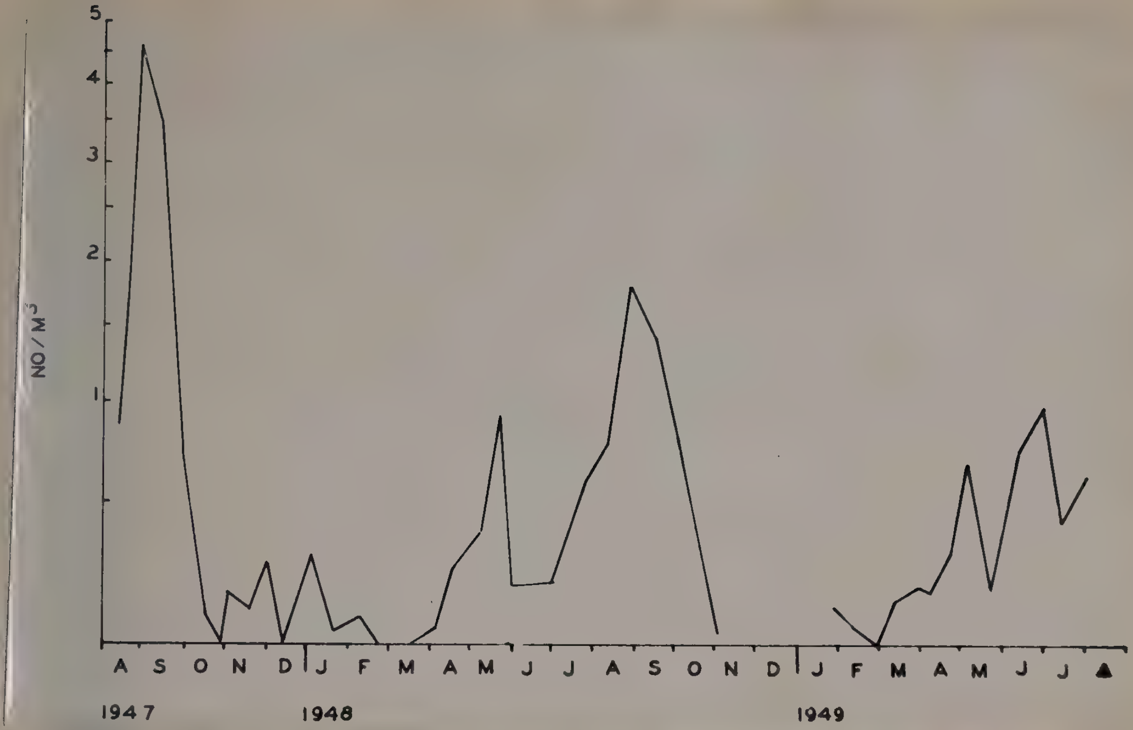


Figure 82. High and low tide means of pelecypod larvae. No/m^3 in thousands.

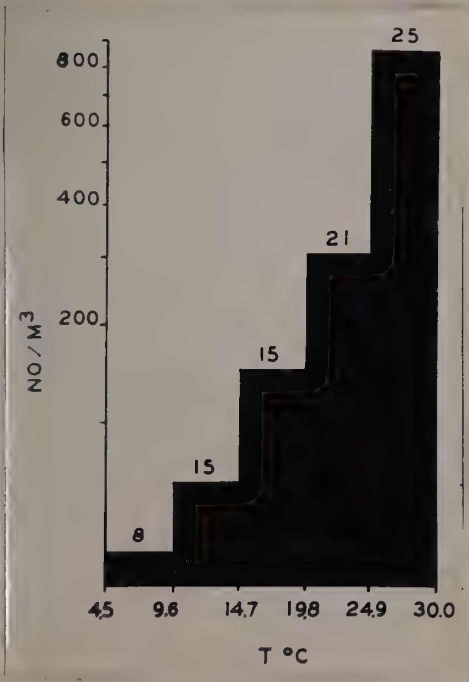


Figure 83. Means of pelecypod larvae with ranges of temperature.

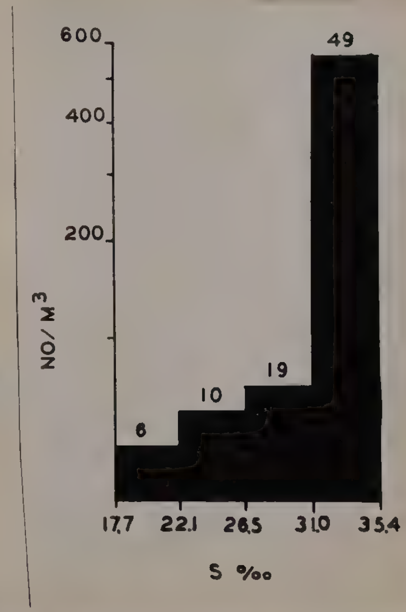


Figure 84. Means of pelecypod larvae with ranges of salinity.

temperatures and salinities (Fig. 83 and 84). The larvae were more prevalent at high tide (304/m^3) than at low tide (136/m^3) Populations and pH are given in Table XXXVII.

Annelid larvae

In Figure 85 may be seen the distribution of the annelid larvae. Most larvae were found at the highest temperatures (Fig. 86), although considerable numbers were found in the lower temperature classes. Generally speaking, annelid larvae were found more frequently at lower salinities (Fig. 87), which is in accordance with the fact that more were found at low tide (159/m^3) than at high tide (85/m^3). More annelid larvae were found around late morning and midday than at other times of the day. In Table XXXVIII may be seen means with values of pH.

Means No/m^3	pH	Number Observations
183	<7.9	4
195	7.9	20
97	8.0	37
105	8.1	14
111	>8.1	4

Table XXXVIII. Means of annelid larvae observed with values of pH.

Cladocerans

Evadne tergestina Claus. This cladoceran was found to be most numerous in summer and early fall (Fig. 88). Figures 39

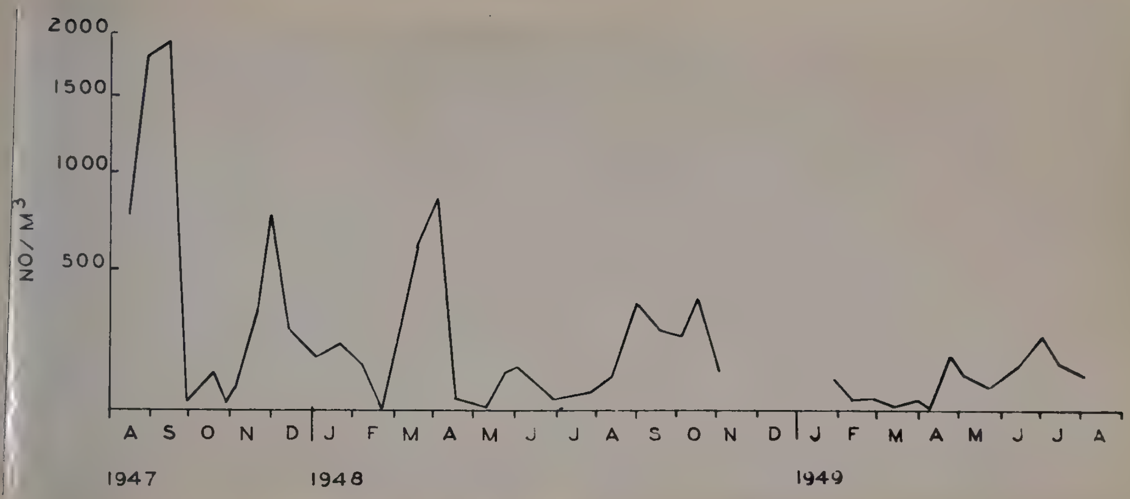


Figure 85. High and low tide means of annelid larvae.

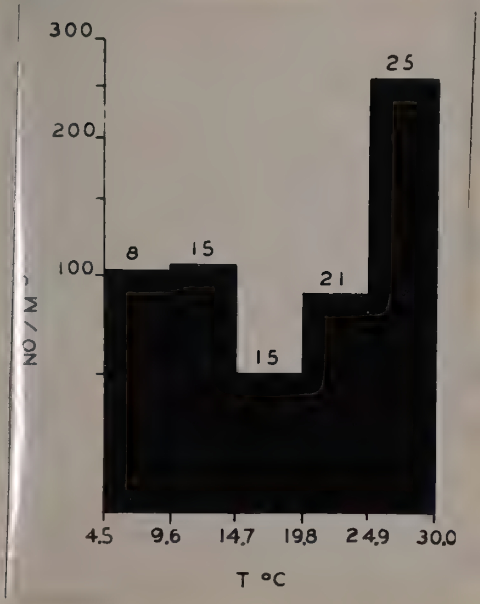


Figure 86. Means of annelid larvae with ranges of temperature.

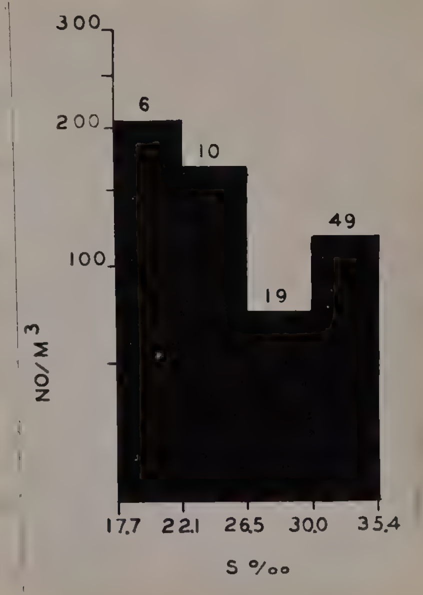


Figure 87. Means of annelid larvae with ranges of salinity.

and 90 show that it was markedly restricted to the higher temperatures and salinities. It was somewhat more numerous at high tide (2.9/m^3) than at low tide (2.1/m^3). Occurrences with pH are shown in Table XXXIX.

Means No/m^3	pH	Number Observations
0	<7.9	4
3.2	7.9	20
2.3	8.0	37
3.3	8.1	14
0	>8.1	4

Table XXXIX. Means of _Evadne tergestina_ observed with values of pH.

Evadne tergestina was found in tow number 7 in Bogue Sound (Table III) and numbers 23, 32, and 36 in the ocean. (Table VII, Fig. 11). Fish (1925) found this species in the summer and fall at Woods Hole. Baker (1938) believes this is essentially a tropical species, as does Cleve (1900).

Penilia schmackeri Richard. _Penilia schmackeri_ occurred most frequently in summer and fall (Fig. 91), and was mostn numerous at high temperatures and salinities (Figs. 92 and 93). The mean concentration at high tide(13/m^3) was greater than that at low tide (5.4/m^3). Numbers of _Penilia schmackeri_ associated with values of pH are given in Table XL.

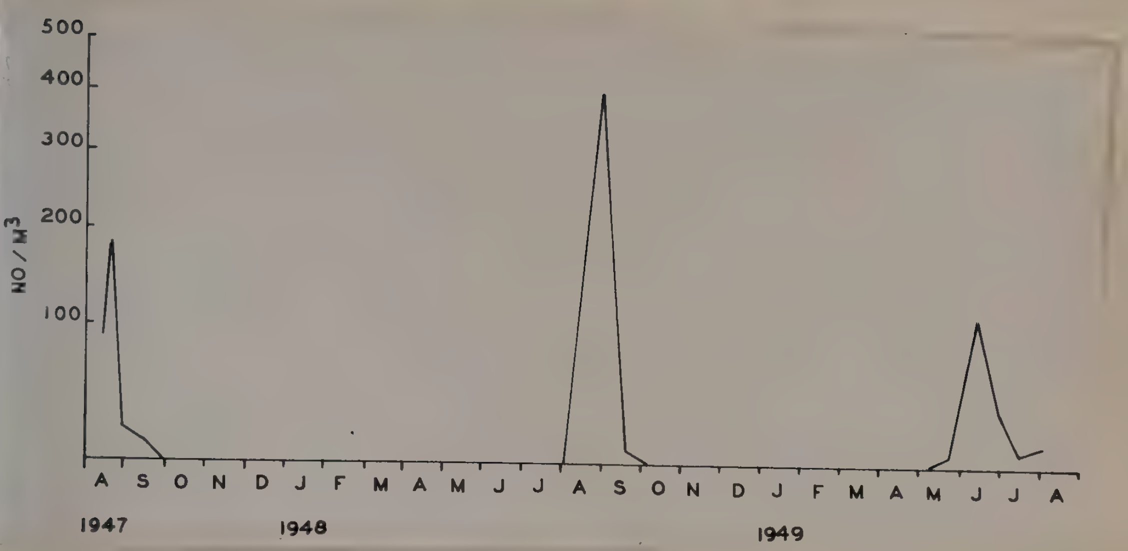


Figure 88. High and low tide means of *Evadne tergestina*.

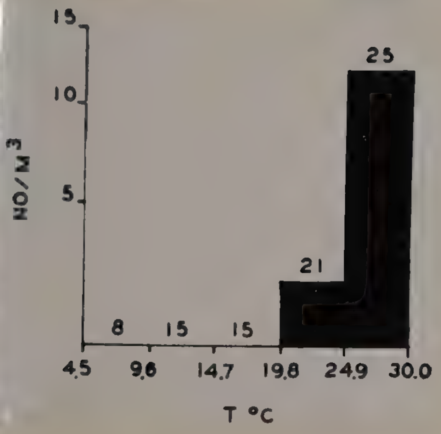


Figure 89. Means of *Evadne tergestina* with ranges of temperature.

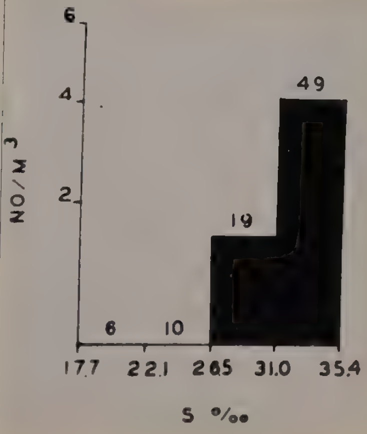


Figure 90. Means of *Evadne tergestina* with ranges of salinity.

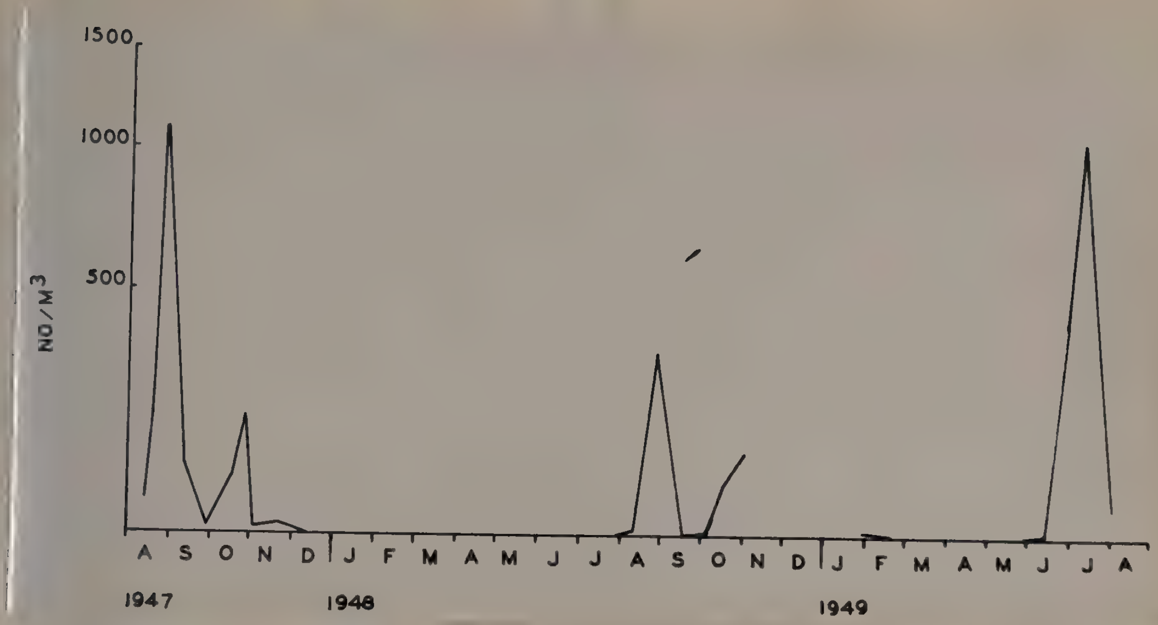


Figure 91. High and low tide means of _Penilia schmackeri_.

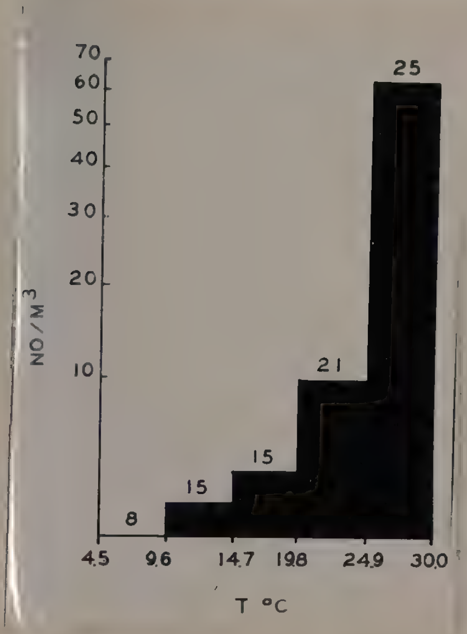


Figure 92. Means of _Penilia schmackeri_ with ranges of temperature.

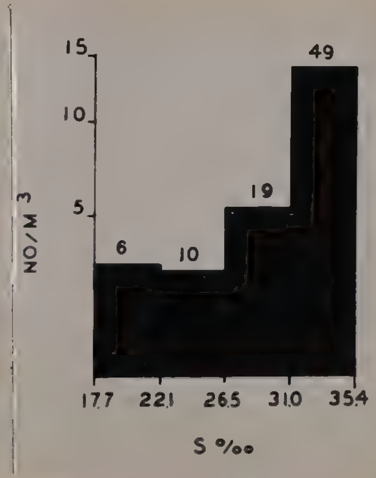


Figure 93. Means of _Penilia schmackeri_ with ranges of salinity.

Means No/m^3	pH	Number Observations
5.9	<7.9	4
5.7	7.9	22
5.3	8.0	37
57	8.1	14
0	>8.1	4

Table XL. Means of *Penilia schmackeri* observed with values of pH.

Penilia schmackeri occurred in tow number 9 in Bogue Sound (Table III), number 19 in Pamlico Sound (Table VI, Fig. 12), and in tows 32, 33, 36, and 39 outside (Table VII, Fig. 11). Sudler (1901) found this species in great numbers in Beaufort Harbor in June of 1896. The occurrences of Penilia in and near the Gulf Stream, together with the fact that higher populations occurred at higher temperatures suggest that this is a tropical species, possibly brought in by the Gulf Stream.

Barnacle larvae

This category includes both nauplii and cyprids. As may be seen in Figure 94, these were most numerous in spring and summer, but there were peaks at other times of the year. The larvae were fairly represented in all temperature classes, the 14.7-19.7°C range being the highest (Fig. 95). Greater numbers were associated with lower salinities (Fig. 96). The mean concentration at low tide (197/m^3) was much greater than that at high tide (20/m^3). Larvae were more frequently

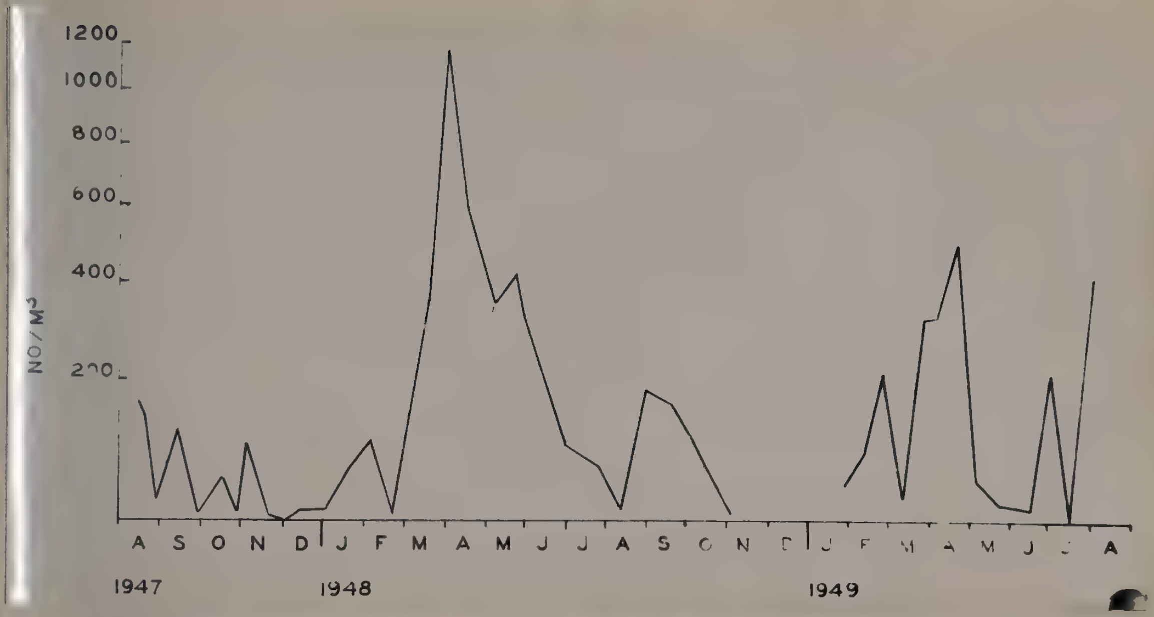


Figure 94. High and low tide means of barnacle larvae.

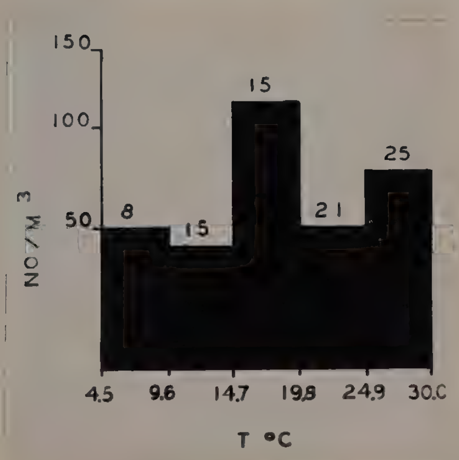


Figure 95. Means of barnacle larvae with ranges of temperature.

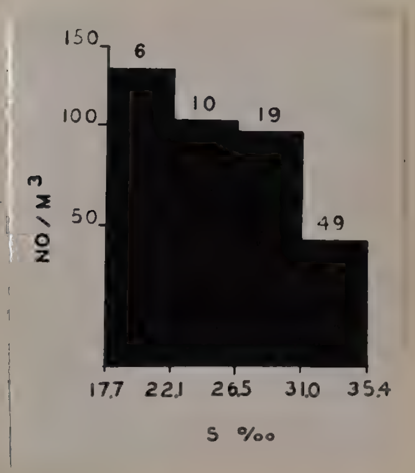


Figure 96. Means of barnacle larvae with ranges of salinity.

encountered in the early afternoon than at other times. Occurrences with pH are given in Table XLI.

Means No/m³	pH	Number Observations
82	<7.9	4
170	7.9	20
48	8.0	37
38	8.1	14
50	>8.1	4

Table XLI. Means of barnacle larvae observed with values of pH.

Gastropod larvae

These were found to be least numerous in the colder months and lower temperatures (Figs. 97 and 98). Greatest numbers were associated with highest salinities (Fig. 99). Slightly higher means were encountered for low tide ($39/m^3$) than for high tide ($31/m^3$). Means with pH may be seen in Table XLII.

Means No/m³	pH	Number Observations
3.5	7.9	4
31	7.9	20
30	8.0	37
152	8.1	14
23	8.1	4

Table XLII. Means of gastropod larvae observed with values of pH.

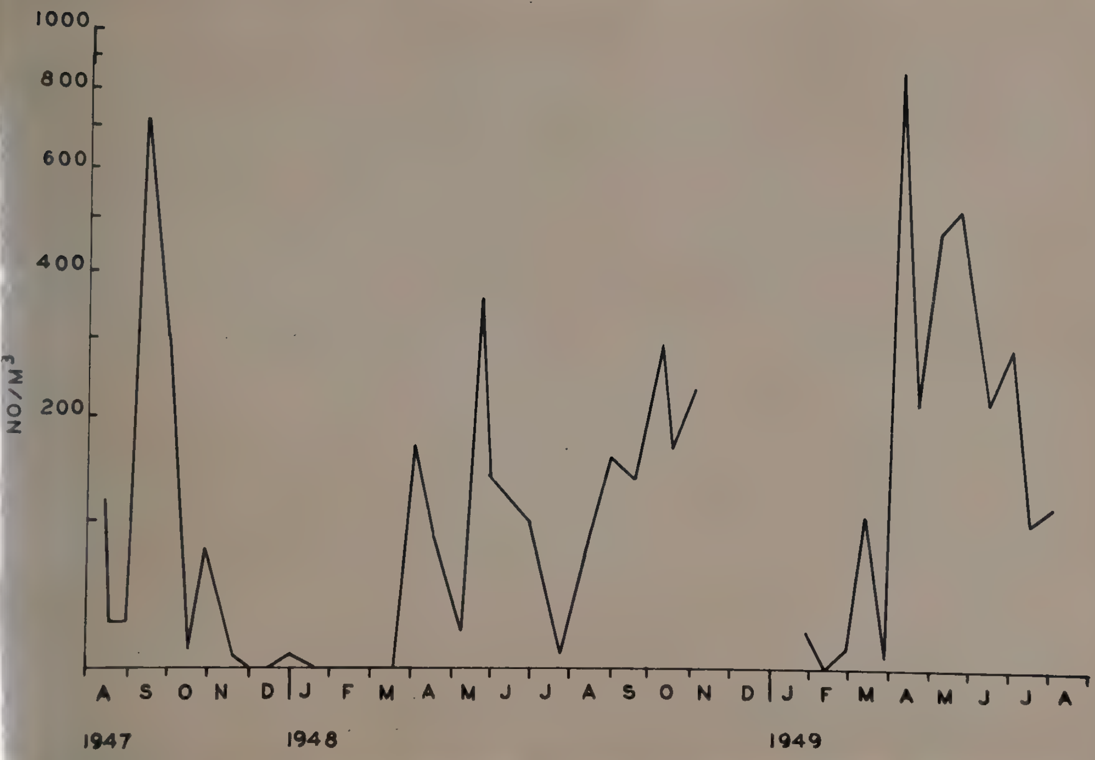
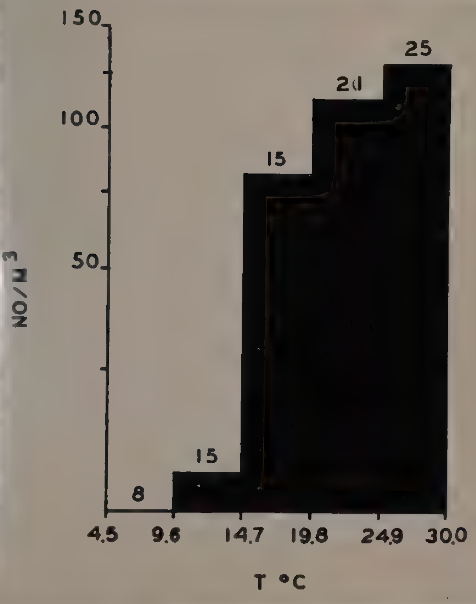


Figure 97. High and low tide means of gastropod larvae.



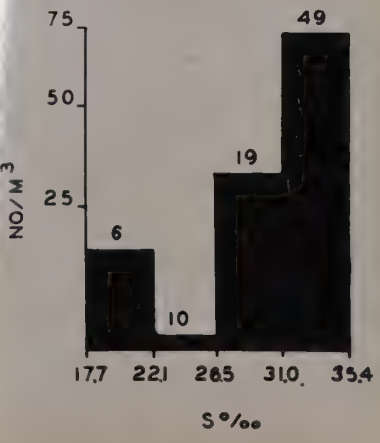


Figure 98. Means of gastropod larvae with ranges of temperature.

Figure 99. Means of gastropod larvae with ranges of salinity.

Tunicate larvae

Tunicate larvae were found at all seasons of the year, (Fig. 100) but were most numerous at high temperatures, (Fig. 101), and high salinities (Fig. 102). The mean concentration at high tide ($32/m^3$) was greater than that at low tide ($19/m^3$). Means and pH were as seen in Table XLIII.

Means No/m^3	pH	Number Observations
2.6	<7.9	4
13	7.9	20
42	8.0	37
51	8.1	14
12	>8.1	4

Table XLIII. Means of tunicate larvae observed with values of pH.

Echinoderm larvae

This group showed a marked peak in late summer and early fall as may be seen in Figure 103. Echinoderm larvae were most numerous at highest temperatures and salinities (Figs.

Means No/m^3	pH	Number Observations
0	<7.9	4
13	7.9	20
12	8.0	37
18	8.1	14
3.4	>8.1	4

Table XLIV. Means of echinoderm larvae observed with values of pH.

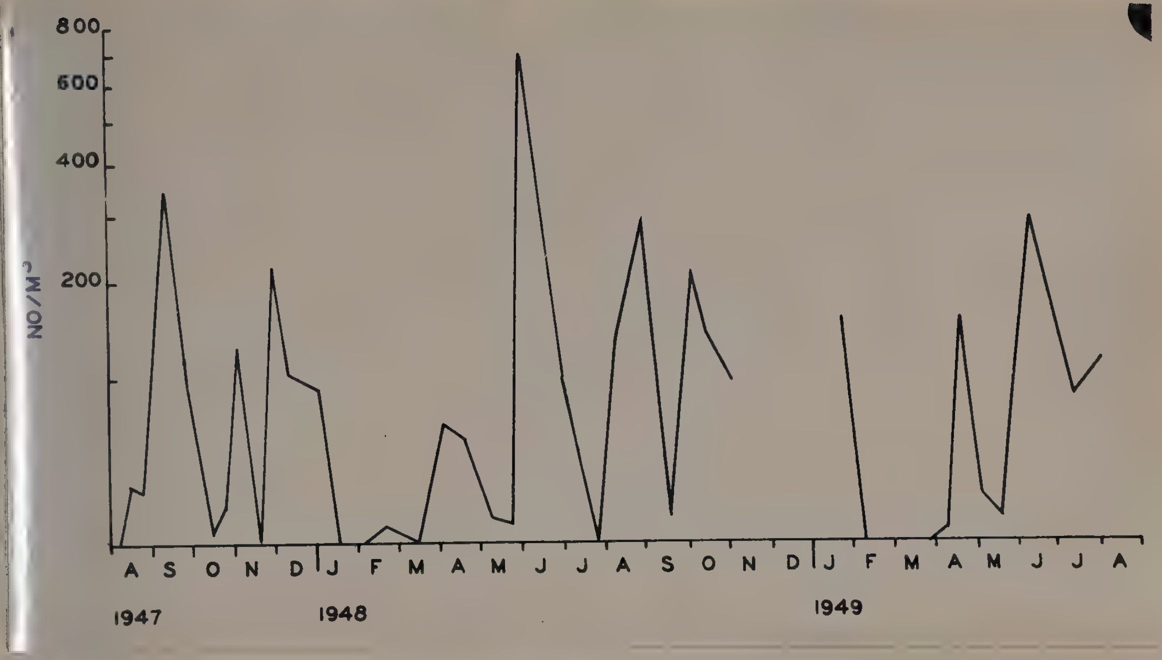


Figure 100. High and low tides means of tunicate larvae.

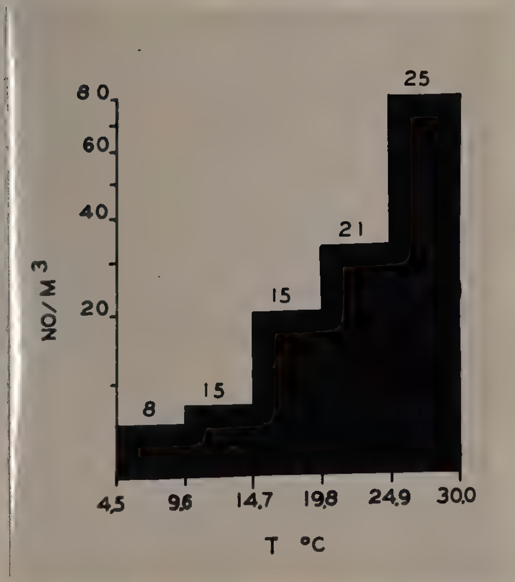


Figure 101. Means of tunicate larvae with ranges of temperature.

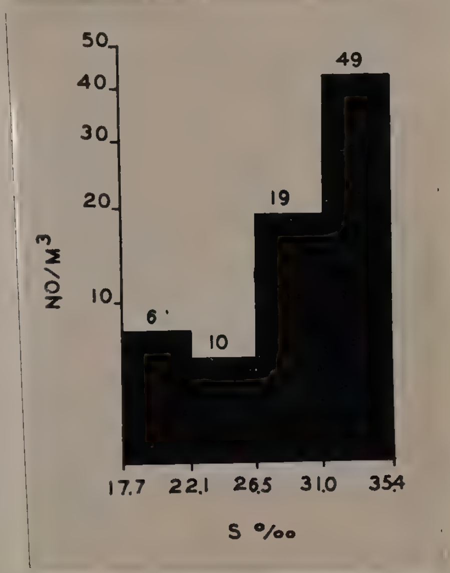


Figure 102. Means of tunicate larvae with ranges of salinity.

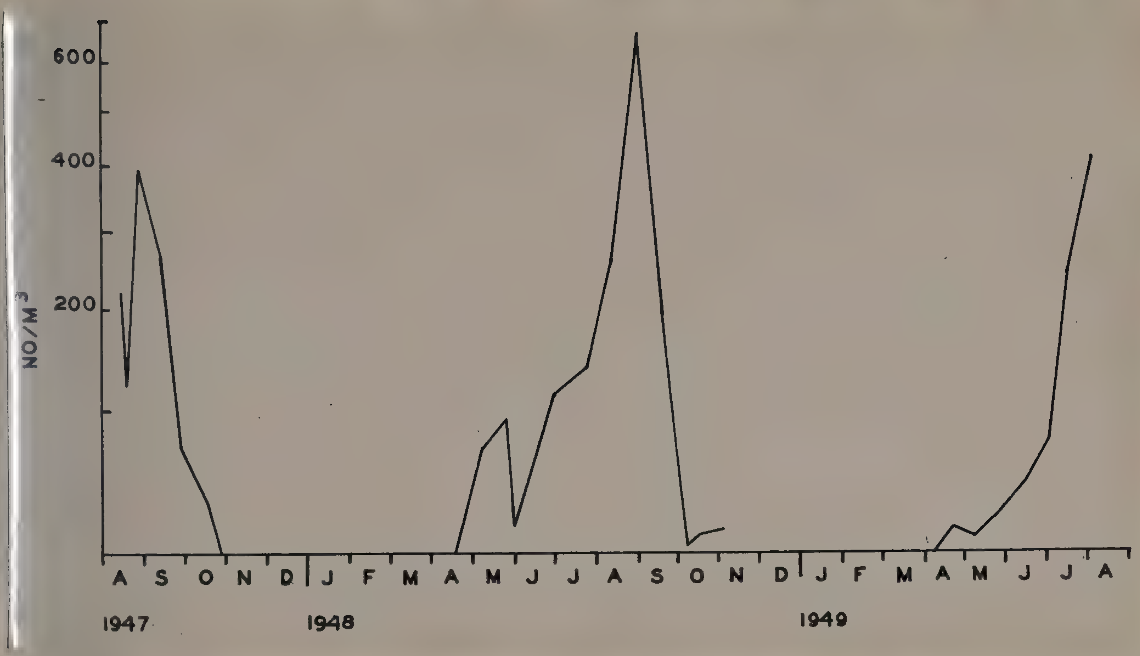


Figure 103. High and low tide means of echinoderm larvae.

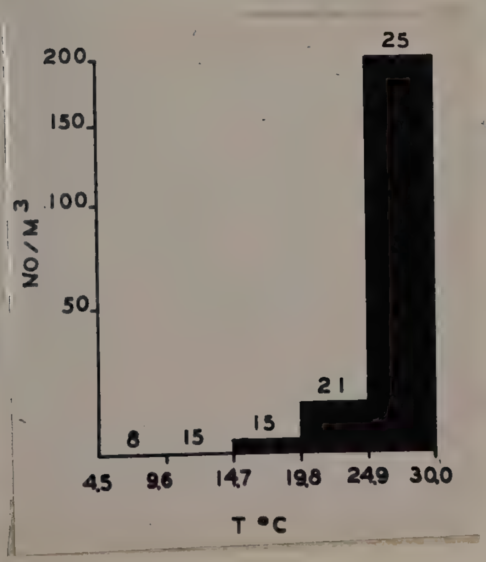


Figure 104. Means of echinoderm larvae with ranges of temperature.

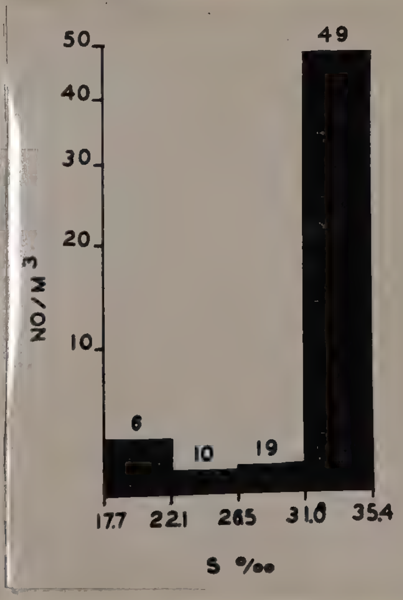


Figure 105. Means of echinoderm larvae with ranges of salinity.

104 and 105). High tides showed greater numbers (19/m^3) than low tides (7.6/m^3). Populations coincident with pH are shown in Table XLIV.

Decapod and stomatopod larvae.

It may be seen in Figure 106 that these were most numerous in the warmer months of the year. They occurred in greatest numbers at high temperatures and salinities (Figs. 107 and 108). There was a correlation with time of day in that greater numbers were encountered in late morning and around midday. More were found at high tide (7.7/m^3) than at low tide (1.5/m^3). Numbers with pH are given in Table XLV.

Means No/m^3	pH	Number Observations
2.6	<7.9	4
8.2	7.9	20
14	8.0	37
3.6	8.1	14
5.1	>8.1	4

Table XLV. Means of decapod and stomatopod larvae observed with values of pH.

Chaetognatha

Except for the winter of 1949, greatest numbers of Chaetognatha were found in summer and fall (Fig. 109). Several samples were identified to species (mostly juveniles) which are indicated on the graph. Figures 110 and 111 show numbers of Chaetognatha with temperature and salinity. Means occurring

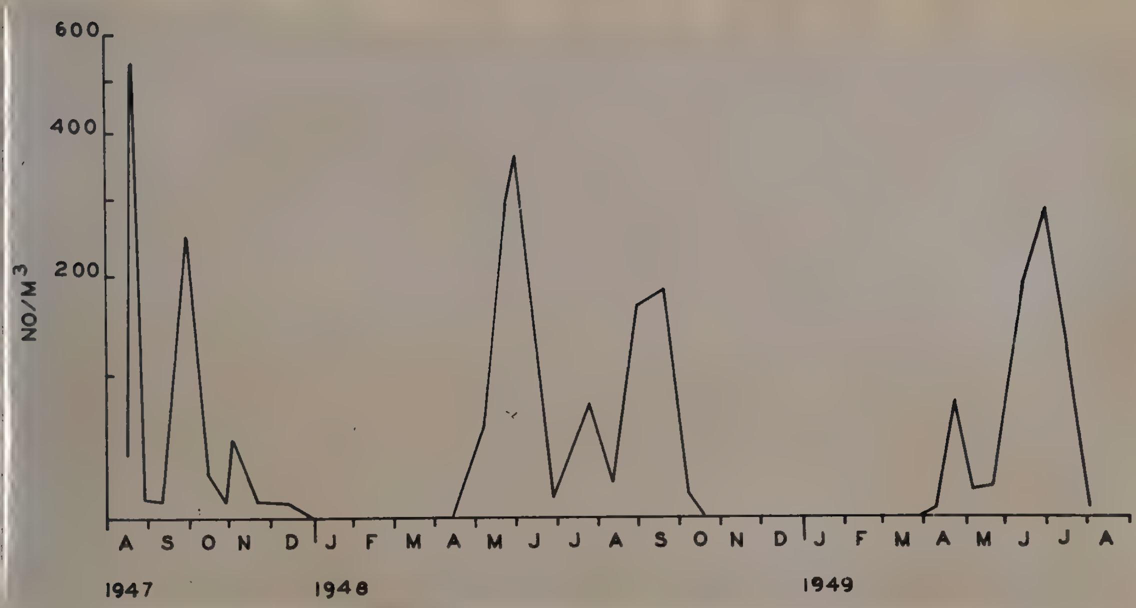


Figure 106. High and low tide means of decapod and stomatopod larvae.

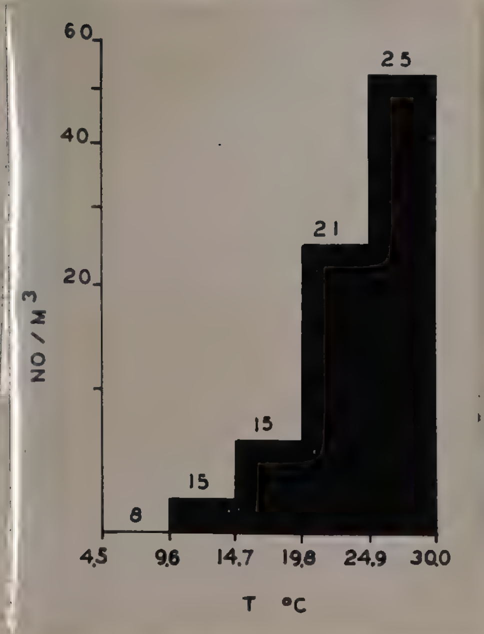


Figure 107. Means of decapod and stomatopod larvae with ranges of temperature.

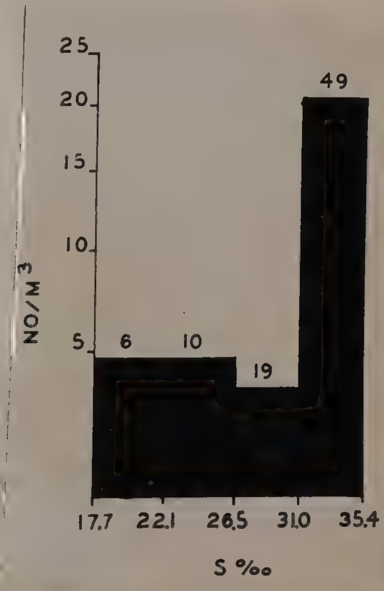


Figure 108. Means of decapod and stomatopod larvae with ranges of salinity.

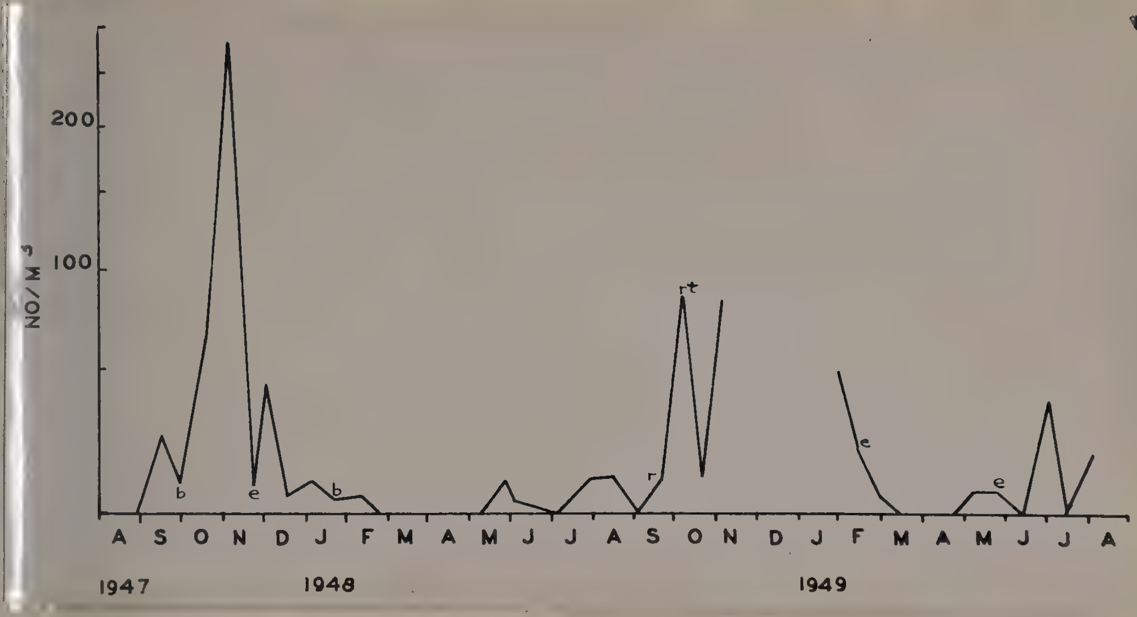


Figure 109. High and low tide means of Chaetognatha. e Sagitta elegans; b S. bipunctata; r S. robusta; t S. tenuis.

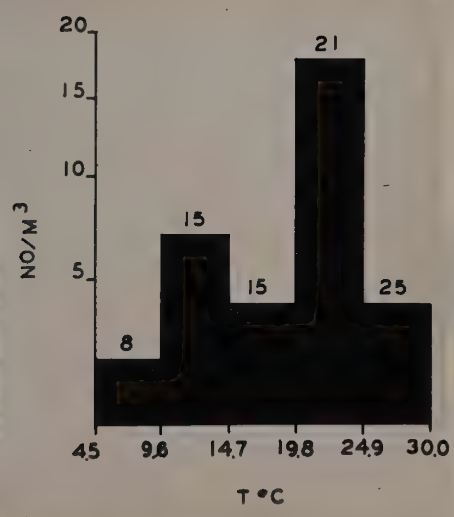


Figure 110. Means of Chaetognatha with ranges of temperature.

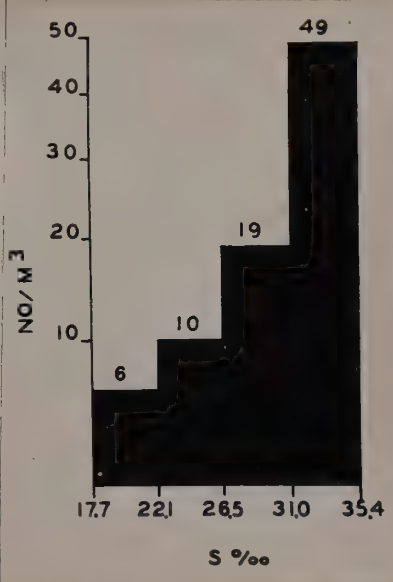


Figure 111. Means of Chaetognatha with ranges of salinity.

with pH are given in Table XLVI. Greater numbers of Chaetognatha were found at high tide ($12/m^3$) than at low tide ($3/m^3$).

Means No/m^3	pH	Number Observations
0	<7.9	4
2.5	7.9	20
6.9	8.0	37
12	8.1	14
7.8	>8.1	4

Table XLVI. Means of Chaetognatha observed with values of pH

No Chaetognatha were found in Bogue Sound or in Pamlico Sound. Outside occurrences were in tow numbers 15, 23, 25, 29-37, and 39 (Table VII, Fig. 11).

The following list gives occurrences of Chaetognatha found in Beaufort Inlet which were identified from the *Albatross III* material:

	Tow No.
Sagitta bipunctata Quoy et Gaimard	34,35
Sagitta elegans Verrill	39
Sagitta robusta Doncaster	34,36
Sagitta tenuis Conant	36

All of the species were obtained in relatively warm water except *S. elegans* which was found in the mixed tow at the edge of the cold water north of Cape Hatteras. It must have been taken in the lower colder layer, for Bigelow (1926) and

Redfield and Beale (1940) consider it characteristic of the northern Atlantic coast.

Nematodes

In Figure 112 may be seen the distribution of nematodes found in the plankton over the time of observations. The graphs of the numbers occurring with temperatures and salinities may be seen in Figures 113 and 114. More nematodes were found at low tide (2.8/m^3) than at high tide (1.8/m^3). Means and values of pH are given in Table XLVII.

Means No/m^3	pH	Number Observations
0	<7.9	4
1.8	7.9	20
2.6	8.0	37
2.6	8.1	14
8.8	>8.1	4

Table XLVII. Means of nematodes observed with values of pH.

Medusae

Medusae were found mostly in summer and fall, as seen in Figure 115. Somewhat greater numbers were found at the higher temperatures (Fig. 116), and at the extremes of salinity (Fig. 117). Mean concentration at high tide (2.0/m^3) was greater than that at low tide (1.5/m^3). Numbers of medusae occurring with pH are found in Table XLVIII.

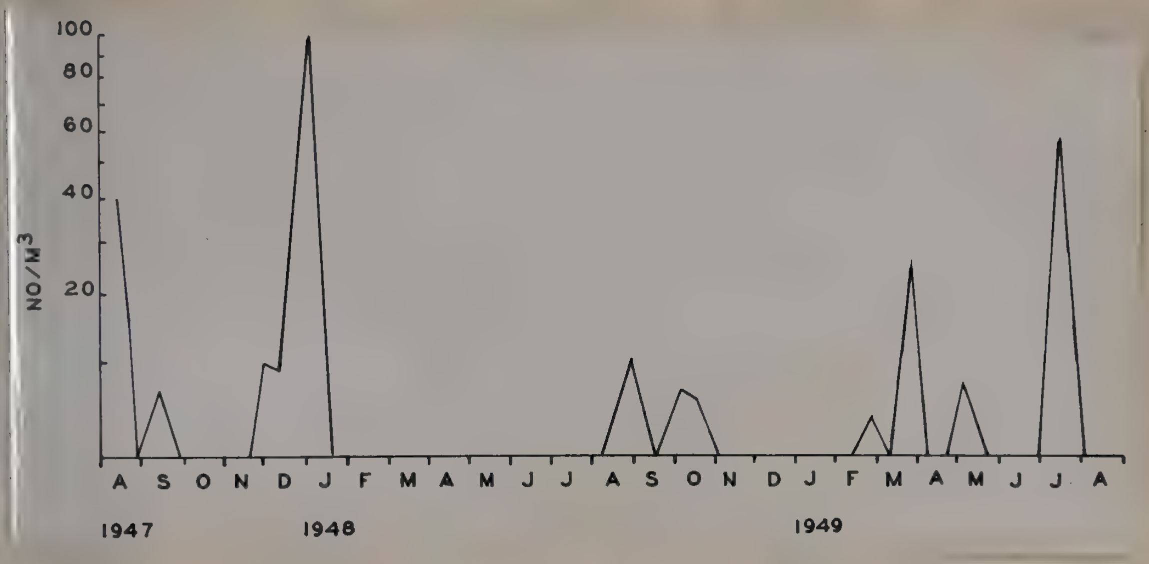


Figure 112. High and low tide means of nematodes.

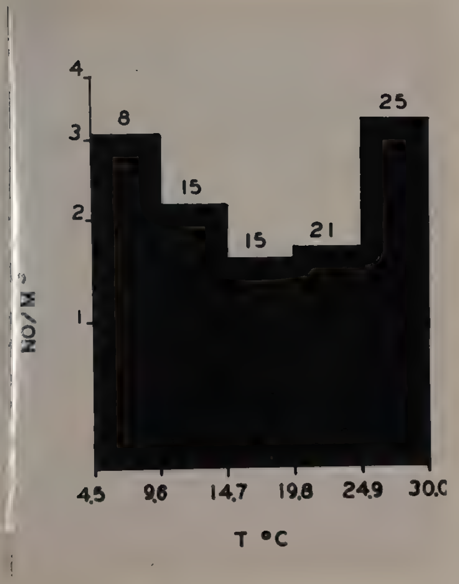


Figure 113. Means of nematodes withe ranges of temperature.

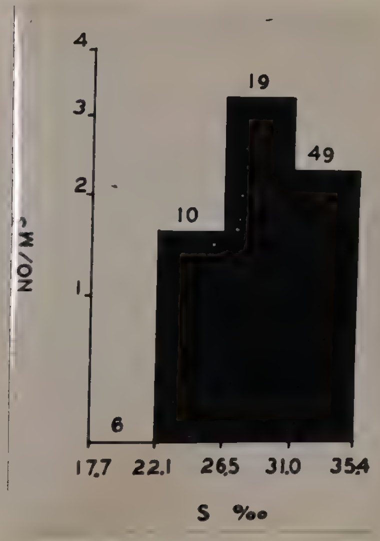


Figure 114. Means of nematodes with ranges of salinity.

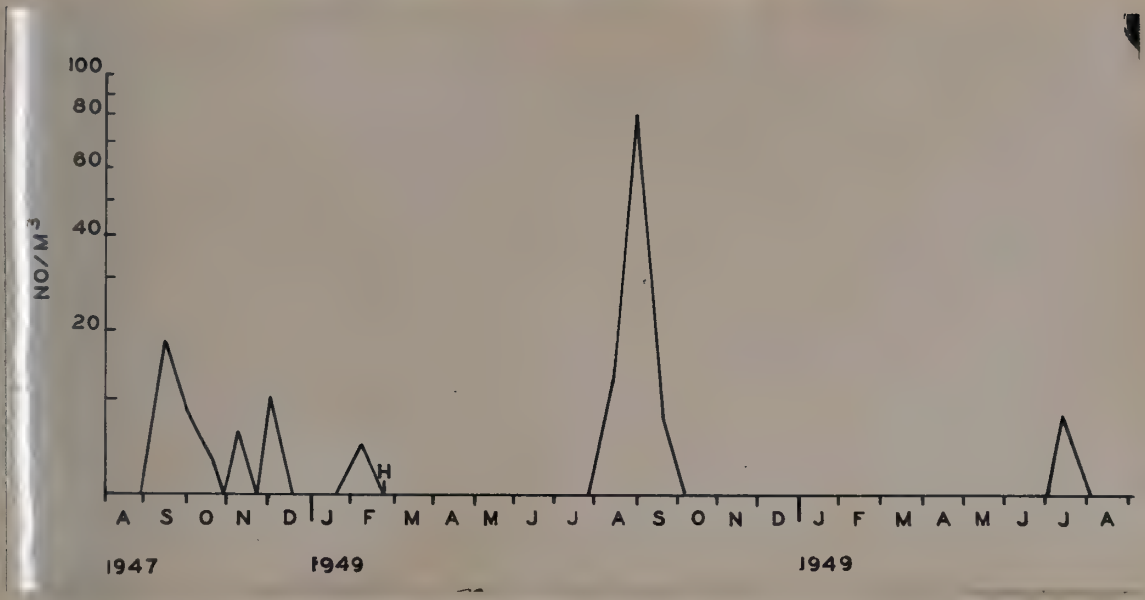


Figure 115. High and low tide means of medusae.

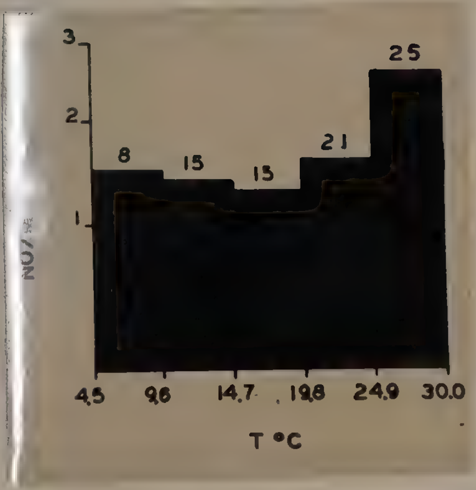


Figure 116. Means of medusae with ranges of temperature.

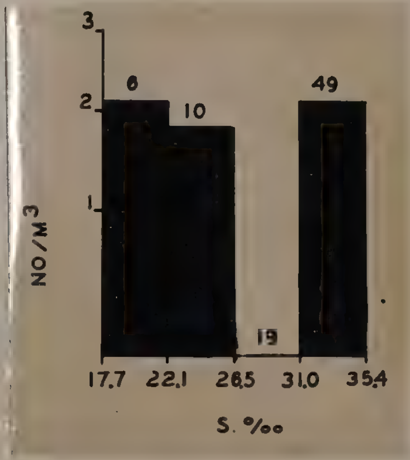


Figure 117. Means of medusae with ranges of salinity.

O.

Means No/m^3	pH	Number Observations
0	<7.9	4
1.8	7.9	20
1.8	8.0	37
1.5	8.1	14
0	>8.1	4

Table XLVIII. Means of medusae observed with values of pH.

Isopods

The occurrence of small isopods was rather infrequent, as may be seen in Figure 118. A few were present at most ranges of temperature (Fig. 119) and salinity (Fig. 120). No correlation with time of day was apparent. Isopods occurred more frequently at low tide (1.9/m^3) than at high tide (1.3/m^3), but only by a small amount. Numbers found with pH may be seen in Table XLIX.

Means No/m^3	pH	Number Observations
0	<7.9	4
1.5	7.9	20
1.7	8.0	37
1.6	8.1	14
0	>8.1	4

Table XLIX. Means of isopods observed with values of pH.

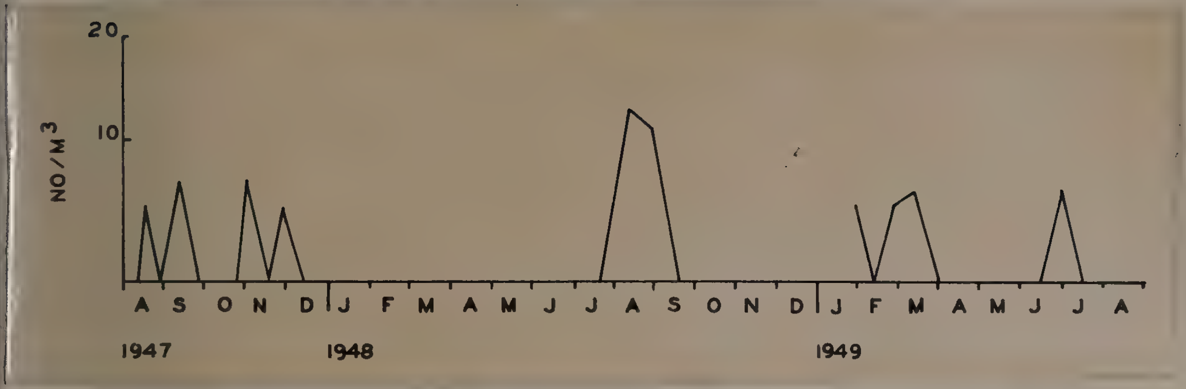


Figure 118. High and low tide means of isopods.

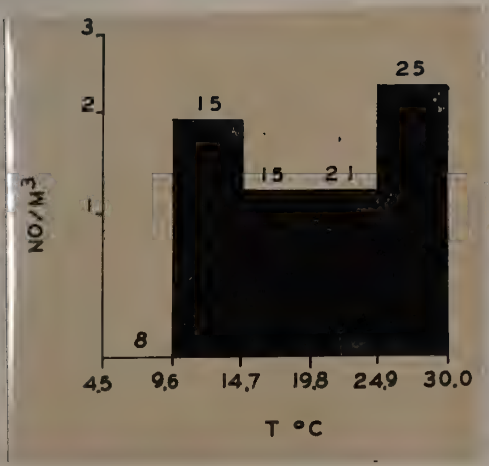


Figure 119. Means of Isopods with ranges of temperature.

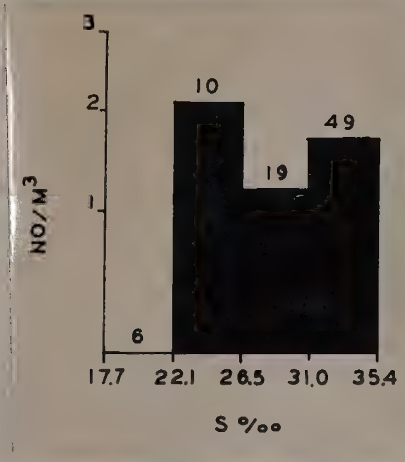


Figure 120. Means of isopods with ranges of salinity.

Ostracods

Ostracods were found on three different occasions. Means together with hydrographic conditions are given in Table L.

Date	Means No/m^3	Water Temp. ^{0}C	Salinity o/oo	Ext. Coef.	pH	Tide
Nov.1,'47	10	20.0	23.3	1.69	8.0	L
Jan.2,'48	17	10.6	31.8	3.09	8.0	H
Nov.4,'48	7.5	19.2	33.5	0.84	8.1	H

Table L. Hydrographic conditions and occurrence of ostracods.

The ostracods of Beaufort Inlet and those from the Albatross III material have been sent to Dr. Willis L. Tressler for identification.

Pelagic tunicates

In Table LI it may be seen that pelagic tunicates occurred mostly in summer and fall. The hydrographic conditions under which they were found are included in this table.

Date	Water Temp. ^{0}C	Salinity o/oo	pH	Ext. Coef.	Tide Stage
Sept.29,'47	21.5	31.8	-	2.42	H
June 30,'48	28.5	34.2	7.9	0.57	H
Sept.19,'48	24.8	35.3	7.9	0.71	H
Oct. 17,'48	19.9	31.1	8.1	0.47	H
Nov. 2, '48	19.2	33.5	8.1	0.84	H
Feb. 27,'49	14.1	31.3	8.1	0.48	H
Aug. 2, '49	28.5	34.8	8.0	0.58	H

Table LI. Hydrographic conditions observed with pelagic tunicates.

Pelagic tunicates from Beaufort Inlet and the ocean have been sent to Dr. A.G. Huntsman for identification.

Pelagic decapods

Lucifer faxoni Borradaile. Lucifer faxoni was found twice in this study, both times being recorded only as present. The occurrences and hydrographic conditions which accompanied them. are given in Table LII.

Date	Water Temp. °C	Salinity o/oo	pH	Ext. Coef.	Tide Stage
Sept.29,'47	21.5	31.8	-	2.42	H
Sept.19,'48	24.4	35.3	7.9	0.71	H

Table LI. Hydrographic conditions observed with *Lucifer faxoni*.

Lucifer typus M. Edwards. This pelagic decapod was found on five occasions which are listed below together with hydrographic conditions in Table LII. Only twice was it present in quantity: Oct. 16, 1947 - 3/m^3, and Aug. 31, 1948 - 7/m^3. It was recorded as present in the other three instances.

No Lucifer of either species was present in any of the Bogue Sound or Pamlico Sound material. The following are occurrences of both species in oceanic collections:

	Tow No.
Lucifer faxoni	33,34,36,37
Lucifer typus	32,33,38,39

Date	Water Temp.°C	Salinity o/oo	pH	Ext. Coef.	Tide Stage
Sept.29,'47	21.5	31.8	-	2.42	H
Oct. 16,'47	22.5	25.4	-	1.80	H
Oct. 16,'47	23.5	19.9	-	2.00	L
Nov. 2, '47	20.0	23.3	8.0	1.69	L
Aug. 31,'48	27.2	34.3	7.9	1.21	L

Table LII. Hydrographic conditions observed with occurrence of *Lucifer typus*.

Cumacea

Oxyurostylis smithi Calman. This animal was found twice; at high tides on February 7,1948 (4.9/m^3) and on November 2, 1948 (7.5/m^3). The hydrographic conditions under which it occurred are given in Table LIII.

Water Temp.°C	Salinity o/oo	pH	Ext. Coef.
7.0	26.3	7.9	0.88
19.2	33.5	8.1	0.84

Table LIII. Hydrographic conditions observed with *Oxyurostylis smithi*.

Siphonophores

Siphonophores were never found to be numerous during the course of the study, and were in every case, recorded only as present. It may be seen in Figure 121 that except for a period during the latter part of 1948 and the early poption of 1949, siphonophores were found in nearly every month of the year.

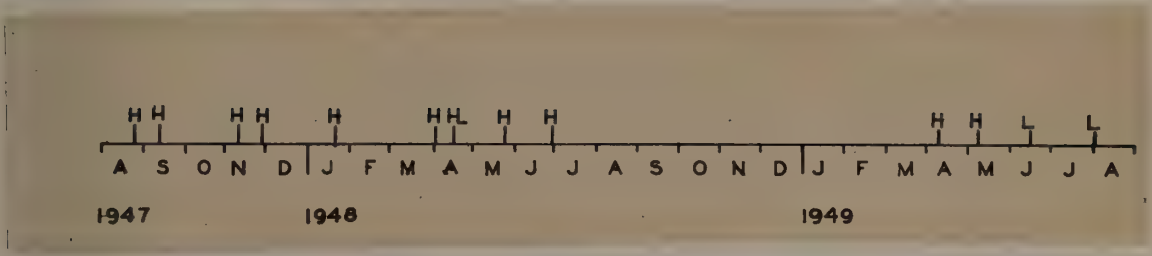


Figure 121. Occurrences of siphonophores. Letters H and L refer to presence at high or low tides.

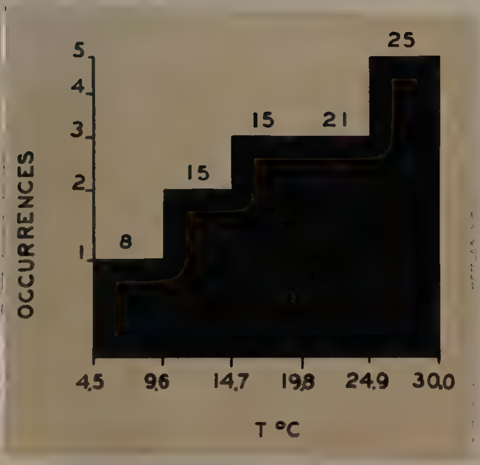


Figure 122. Occurence of siphonophores with ranges of temperature.

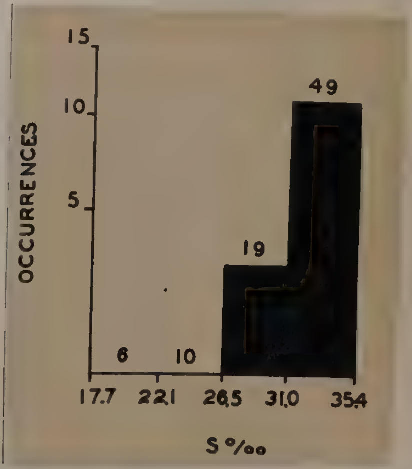


Figure 123. Occurrence of siphonophores with ranges of salinity.

However, Figures 122 and 123 show that this group occurred more frequently at higher temperatures and higher salinities. Of the 14 occurrences, 11 occurred at high tide. Occurrences and values of pH are given in Table LIV.

No. of Occurrences	pH	Number Observations
0	<7.9	4
5	7.9	20
5	8.0	37
3	8.1	14
1	>8.1	4

Table LIV. Occurrences of siphonophores coincident with values of pH.

Siphonophores from Beaufort Inlet and the ocean have been sent to Dr. Mary Sears for identification.

Related Areas

The material found in the following sections dealing with areas adjacent to Beaufort Inlet does not include those species of animals common to both these areas and Beaufort, because they have already been discussed in the previous section.

Bogue Sound

The percentage composition of the zooplankton of Bogue Sound is given in Table LV. Dates and ecological data accompanying these tows are given in Table III.

Organisms	% Total Zooplankton
Copepods, copepodids	35.6
Copepod nauplii	21.2
Annelid larvae	14.7
Gastropod larvae	8.4
Pelecypod larvae	7.9
Barnacle larvae	5.7
Nematodes	3.2
Tunicate larvae	1.6
Cladocerans	1.4
Echinoderm larvae	0.2
Decapod, stomatopod larvae	0.1

Table LV. Percent composition of total zooplankton in Bogue Sound (Table III).

There were no animals identified to species in Bogue Sound which have not already been discussed under "Beaufort Inlet."

Pamlico Sound

Organisms	% Total Zooplankton
Copepod nauplii	51.5
Copepods	34.1
Barnacle larvae	10.3
Cladocerans	2.8
Pelecypod larvae	0.6
Annelid larvae	0.3
Echinoderm larvae	0.2
Tunicate larvae	0.1

Table LVI. Percent composition of total zooplankton in Pamlico Sound (Table VI, Fig. 11).

In Table LVI may be seen the percent composition of the zooplankton of Pamlico Sound. This is a compilation of tows 10-14. Dates and ecological data accompanying these tows are given in Table VI (see also Fig. 11).

The remainder from Table LVI was composed of small numbers of gastropod larvae, decapod and stomatopod larvae, and isopods. The only occurrence in Pamlico Sound of an animal identified to species other than those mentioned under "Beaufort Inlet" was that of Podon polyphemoides (Leuckart), a cladoceran, in tows 10 and 11 (Table VI, Fig. 11).

Outside

Organisms	% Total Zooplankton
Copepods, copepodids	44.3
Copepod nauplii	41.2
Tunicate larvae, Larvacea	5.1
Pelecypod larvae	3.6
Annelid larvae	2.3
Gastropod larvae	1.6
Chaetognatha	0.8
Medusae	0.2
Barnacle larvae	0.2
Echinoderm larvae	0.2
Pteropods	0.2
Cladocerans	0.1
Pelagic tunicates	0.1

Table LVII. Percent composition of zooplankton in the ocean, tows 15-32 (Table VII, Fig. 11).

Table LVII shows the percent composition of the total zooplankton of tow numbers 15-32 (Table VII, Fig. 11) taken

by investigators of the Institute of Fisheries Research aboard the Penny. Counts of tows 33-40 from the Albatross III are not included because of the large mesh net used.

The remainder of Table LVII was composed of small numbers of nematodes, fish larvae, pelagic decapods, decapod and stomatopod larvae, and siphonophores.

The following list gives species found in the ocean and the tow numbers in which they occurred. Those marked with an asterisk (*) have not been previously reported from North Carolina.

	Tow numbers (Table VII; Fig.11)
Molluscs	
Clio acicula (Rang)	33,34,39
Clio pyramidata Linne	33,37
Limacina trochiformis (Orbigny)	39
Cladocerans	
Evadne spinifera Müller	34,35
Copepods	
*Acartia clausi hudsonica Pinhey	19,20
Acartia danae Giesbrecht	33
*Acrocalanus longicornis Giesbrecht	30,33,37
Anomalocera ornata Sutcliffe	29,30
*Calanopia americana F. Dahl	35
*Calanus finmarchicus (Gunner)	20,22,38
Calocalanus pavo (Dana)	33,34,36,37
*Calocalanus styliremis Giesbrecht	23,25,34
*Candacia bispinosa Claus	40
*Candacia pachydactyla (Dana)	33,37
*Centropages violaceus (Claus)	37
*Clausocalanus arcuicornis (Dana)	36,39
*Copilia mediterranea (Claus)	40
*Copilia mirabilis Dana	33,37,40
*Copilia quadrata (?) Dana	40
*Corycaeus latus Dana	32,36,37,39
*Corycaeus lautus Dana	33
*Corycaeus speciosus Dana	29,33,37

	Tow numbers (Table VII, Fig.11)
*Euaetideus giesbrechti Cleve	33
Eucalanus attenuatus (Dana)	34,37,40
Eucalanus elongatus (Dana)	37
Euchaeta marina (Prestandrea)	33,35,37
*Euchirella amoena Giesbrecht	33
*Farranula carinata (Giesbrecht)	23,25,30,33,34,36,37, 39
*Haloptilus longicornis (Claus)	37
*Heterorhabdus papilliger (Claus)	33
*Labidocera acutifrons (Dana)	37
*Labidocera nerii (Krőyer)	33
*Lubbockia squillimana Claus	33,37
*Lucicutia flavicornis	36,37
*Macrosetella gracilis (Dana)	32,33,34,36,37
Mecynocera clausi Thompson	33,35,36,37,40
Metridia lucens Boeck	33
*Neocalanus gracilis (Dana)	33
*Neocalanus robustior(Giesbrecht)	37
*Neocalanus tenuicornis (Dana)	40
*Oithona linearis (?) Giesbrecht	37
*Oithona robusta Giesbrecht	40
*Oithona setigera (Dana)	33,36,37
*Paracalanus aculeatus Giesbrecht	32,33,36,37,39
*Pontellina plumata Dana	33,34
Pseudocalanus minutus (Krőyer)	17,20,21,22,38,39
*Rhincalanus cornutus Dana	33
*Sapphirina nigromaculata Claus	33,36,37
*Scolecitaricella ctenopus (Giesbrecht)	37
Scolecithrix danae (Lubbock)	33
Temora longicornis (Müller)	17,20,38
Undinula vulgaris (Dana)	23,33,34,35,37,39

Amphipods

Anchylomera blossevillei M.Edwards	37
Brachyscelus crusculum Bate	33
Hyperia bengalensis (Giles)	32,33,36,37,39,40
Hyperia crucipes Bovallius	33
Hyperia galba (Montagu)	33
Lycaea pulex Marion (?)	33,34,
Paralycaea sp.	33
Phronimopsis spinifera Claus	33
Stenothoe galensis Walker	36
Themisto sp. (juv.)	38,39
Tiron australis Stebbing	35
Vibilia sp.	33

Chaetognatha

Sagitta enflata Grassi	33,34,35,36,37
Sagitta serratodentata Krohn	33,37

DISCUSSION

Total zooplankton at Beaufort was found to be generally at its lowest during the colder months of the year with increasing numbers as the temperature got warmer. A similar situation was found by Clarke (1940) in coastal water off Long Island. This increase in the warmer months is apparently due to the presence of greater numbers of copepods together with the appearance of considerable numbers of temporary plankters in the form of developmental stages of various groups. All of the groups representing purely larval forms, except two (tunicate larvae and annelid larvae), were found to be most abundant in spring, summer and fall. Morse (1947) found the same to be true in Chesapeake Bay in that immature forms were generally most numerous in the warmer months of the year.

Total zooplankton was found to be most abundant at high salinities and tides. This trend does not seem to be due to any groups in particular but seemed to be generally true of most of the groups counted. The greatest number of copepods

at high salinities and high tides might indicate in this particular case that the majority of copepods was derived from outside sources from Beaufort Inlet. This has more meaning when considered with temperatures and geographical distribution. Most of the animals generally considered to be permanent plankters were associated with high salinities and tides. All of the developmental stages but three were most numerous at high salinities and high tides. With annelid larvae and particularly barnacle larvae, the reverse was found to be true. Gastropod larvae were different in that although they were most numerous at higher salinities, greater numbers were found at low tides. It is not known at present what percentage of the larval stages at Beaufort represents reproduction of local species and what portion represents influx from other areas.

It should be stated that there are so many factors acting on the organism in the ocean, and the interaction of these is so complex that it is not safe to say that a given effect is due directly to any one factor without the supplement of controlled experiments.

Some of the copepods and cladocerans may be divided into two main groups with respect to the occurrence at Beaufort Inlet. The first of these, the summer-fall group, consists of species occurring in summer and frequently lasting into the fall. The following is a listing of summer-fall species which are found at Beaufort: *Centropages furcatus*, *Euterpina acutifrons*, *Labidocera aestiva*, *Oithona plumifera*, *Oncaea venusta*, *Paracalanus parvus*, *Temora turbinata*, *Evadne tergestina*, and *Penilia*

schmackeri. Also to be included possibly under summer-fall species because of distribution records ar occurrences in the Gulf Stream are *Eucalanus subcrassus* and *E. pileatus*, *Nannocalanus minor*. *Pontella meadii*, and *Temora stylifera*.

The second group consists of species occuring most abundantly in the winter and spring. These are *Centropages hamatus*, *Centropages typicus*, and *Oithona similis*.

It may be seen that the majority of these species of copepods and cladocerans are of tropical origin with respect to temperature and geographical distribution. The temperature factor, according to Sewell (1948), is the greatest single influence on the distribution of copepods. It is significant that Williams (1948) found a somewhat similar type of occurrence of marine algae at Cape Lookout, about 10 miles southeast of Beaufort Inlet: "This locality supports a permanent flora in which tropical species predominate, being augmented by an annual winter-spring flora with northern affinities and an~~d~~ annual summer-fall flora with tropical affinities."

Copepods of intermediate or uncertain status are the following: *Corycaeus amazonicus*, *Corycaeus americanus*, *Microsetella norvegica*, *Oithona brevicornis* and *O. nana*, *Oithona spinirostris*, and *Pseudodiaptomus coronatus*.

On the basis of the evidence found, only one species of copepod (with the possible exception of Hemicyclops) might be thought to be a more or less permanent or indigenous species. This is *Acartia tonsa*. Not only was this copepod found throughout the period of investigation, but it was

also relatively abundant in all temperature ranges. In addition, it was evidently capable of tolerating wide ranges of salinity, as indicated by occurrences at low salinities in Pamlico Sound. It was found more frequently at low tides than at high.

If the temperature ranges of greatest abundance of the summer-fall and winter-spring species be compared to those of the three regions as found in Figure 3, it may be seen that the ranges of these species at Beaufort fall within the temperatures which approach the supposed origin of these species. Thus the temperature ranges of greatest abundance of tropical species lie within that portion of the temperature at Beaufort which approximates conditions at Miami Beach, and the temperature ranges of greatest abundance of northern(or north temperate) species lie within those of Beaufort which approximate conditions at Woods Hole.

The question now arises as to how these species get to Beaufort at the time of the year at which they are found. It is thought that the tropical forms are brought north by the Gulf Stream (Fig. 12) and come into Beaufort Inlet by eddies. If the temperature is cold they may not survive, and so are found but rarely in winter. There is, of course, the possibility that some of these may winter over in a developmental stage.

The cold water types, on the other hand, present something what more of a problem. It is doubted that they survive the summer temperatures, for Sewell (1948) states that it is more difficult

for cold water copepods to survive in warmer waters than the reverse. Also, for two of the winter-spring species, no copepodid stages were found in summer. This is the type of stage in which *Calanus finmarchicus* is known to exist under unfavorable conditions (Johnson and Olson 1948).

The presence of a mass of cold water was shown to be extant just north of Cape Hatteras by the data taken during May and June 1949 by the *Albatross III* (Bumpus, private communication). This is thought to be the southern limit, at that particular time, of the south-flowing coastwise counter current to the Gulf Stream. A plankton tow (No. 38) taken early in June, 1949 in this cold water showed species of copepods generally thought to be typical of the Woods Hole area (*Calanus finmarchicus*, *Centropages hamatus*, *C. typicus*, *Metridia lucens*, *Oithona similis*, and *Pseudocalanus minutus*.).

Scattered plankton tows taken from the *Penny* from north of Cape Hatteras to the South Carolina line earlier in the same year (Feb., Mar., Apr.) showed some of these same species distributed along the coast to the extent of the area investigated. Unless these northern species existed in some form which was not recognized and appeared only under appropriate conditions, which seems unlikely, they could have reached these places only by means of water currents and by two possible routes. Currents must have carried them southward between the northward-flowing Gulf Stream and the shore. In view of the low salinities encountered in Pamlico Sound, and the uncertain character of the water currents which must

exist there, it is not likely that the copepods were brought down through the sounds. They must, therefore, have been carried around Cape Hatteras by a current of water such as that indicated by the schematic diagram (Fig. 12) taken from Bumpus and Wehe (1949). However, the causative factor in changing this condition to that found from the Albatross III in May and June where no circum-Hatteras circulation was indicated, remains to be explained. This may very well be the result of the prevailing winds at Cape Hatteras, as already discussed under "Hydrographic Observations." For it is at this time of year that the winds shift from northerly (which would tend to cause circulation around Cape Hatteras), to southerly which would tend to hinder such circulation.

Once around Cape Hatteras the copepods are evidently carried on down fairly close to shore by the successive eddies where they were found at Beaufort Inlet or points south. If the tentative explanation of the distribution of copepods on the Carolina coast is correct, it lends support to the theory of Bumpus and Wehe (1949) concerning local circulation.

Certain of the tows taken in the ocean were found to contain mixtures of northern and tropical forms (nos. 17, 25, 28, 29, 30, 31, and 39). Most of these were probably a result of a mixing of the Gulf Stream eddy material with the northern counter current population which was brought down from around Cape Hatteras. In tow number 39, however, the situation is somewhat different. This particular sample was taken (Fig. 11) near the edge of the southern limit of the counter current

wherein the warmer local waters overlay the colder water from the north resulting in a marked stratification in temperature (See "Hydrographic Observations"). A vertical tow, taken from near the bottom through the two layers of water, sampled both kinds of populations resulting fn a mixture. Tow 37, a few miles to the south, showed a completely tropical population while tow 38 to the north was completely northern in make up.

SUMMARY

Surface plankton samples were taken at approximately semimonthly intervals at Beaufort, North Carolina, over a period of two years. Supplementary collections were examined from Bogue Sound, Pamlico Sound, and from the ocean adjacent to Beaufort Inlet.

Observations also were made of the ecological factors, such as temperature, salinity, transparency, pH and general meteorological conditions. Temperature was found to range from 4.5-29.9°C, average of 19.7; salinity ranged from 17.7-35.4o/oo, average of 30.3; transparency ranged from 0.46-3.09 (extincion coefficient), average of 1.03; pH ranged from 7.3-8.3, average of 7.9 (most values were 7.9-8.1).

Counts were made of the Beaufort samples of the groups encountered in the zooplankton exclusive of protozoans and ctenophores. An average of 12,217 animals per cubic meter was found for the entire period of study and it was found that the zooplankton was generally more abundant in the warmer months

of the year. The groups enumerated, together with the percent of total zooplankton, and time of greatest abundance were: copepods and copepodid stages 59.52%, spring, summer, and fall; copepod nauplii 20.80%, spring, summer, and fall; pelecypod larvae 6.20%, spring, summer, and fall; annelid larvae 3.11%, peaks occurred throughout the year but highest in warmer months; cladocerans 2.74%, summer and fall; barnacle larvae 2.23 %, spring and summer; gastropod larvae 1.56%, spring, summer, and fall; tunicate larvae 1.38%, peaks occurred at many times of the year but those in summer and fall were highest; echinoderm larvae 0.86%, summer and fall; decapod and stomatopod larvae 0.83%, spring, summer, and fall; Chaetognatha 0.42%, fall and winter; nematodes 0.12%, peaks not particularly restricted to one time of year; medusae 0.11%, summer and fall;. In addition to these, small numbers of isopods, ostracods, pelagic tunicates, pelagic decapods, cumaceans, and siphonophores were found. Others not occurring at Beaufort Inlet but found in the ocean were pteropods, Larvacea, and pelagic amphipods.

Of the groups mentioned, copepods, cladocerans, Chaetognatha, pelagic decapods, cumaceans, pteropods, and pelagic amphipods were identified to species. For the entire study, the number of species found in these groups were: copepods- 72, cladocerans- 4, Chaetognatha- 6, pelagic decapods- 2, cumaceans- 1, pteropods- 3, pelagic amphipods- 9; a total of 97 species.

Attempts were made to show correlations between the ecological factors observed and the various groups counted in the

zooplankton. The factor of phytoplankton as food for zooplankters was not given special considerations, but the peaks of abundance generally coincided. It does not seem feasible to interpret the factors of pH and transparency at this time.

The three main groups of copepods in the zooplankton were found to occur in the following percentages: calanoids 57.78%, cyclopoids 37.69%, and harpacticoids 4.53%. Twenty four species of copepods were identified from Beaufort Inlet in the course of the study, all of which were new to North Carolina. Each species was considered separately with respect to fluctuations in time and occurrences with ecological factors. Summer-fall species at Beaufort which occur in tropical regions are: *Centropages furcatus*, *Euterpina acutifrons*, *Labidocera aestiva*, *Oithona plumifera*, *Oncaea venusta*, *Paracalanus parvus*, and *Temora turbinata*. Although the following species occurred infrequently at Beaufort, they have been reported from tropical regions: *Eucalanus subcrassus* and *E. pileatus*, *Nannocalanus minor*, *Pontella meadii*, and *Temora stylifera*. Winter-spring species at Beaufort, which were commonly found at Woods Hole were: *Centropages hamatus*, *Centropages typicus*, and *Oithona similis*. Those of uncertain status are the following: *Corycaeus amazonicus*, *Corycaeus americanus*, *Microsetella norvegica*, *Oithona brevicornis*, *Oithona nana*? *Oithona spinirostris*, and *Pseudodiaptomus coronatus*. One species, *Acartia tonsa*, is thought to be indigenous. In addition to the species found at Beaufort, 48 different species of copepods were found in the ocean, 36 of which have

not previously been reported from North Carolina. A possible explanation was given as to how the copepods appeared at Beaufort at the time of the year at which they were found. It is thought that the tropical species are brought northward by the Gulf Stream and shunted inshore by eddies between the Gulf Stream and the shore. The northern species are possibly brought down from a cold water counter current to the Gulf Stream which was found north of Cape Hatteras. This necessitates a change in the circulation around Cape Hatteras which might be due to concurrent changes in prevailing winds. Once around Cape Hatteras the cold water copepods would be carried on down the coast by the successive eddies according to the theory of Bumpus and Wehe (1949). The distribution of the copepods studied from February to July, 1949 off the North Carolina coast lends support to this theory of circulation.

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University Fellow, Duke University, Septamber, 1948 to June, 1949.
Investigator, North Carolina Institute of Fisheries Research, May, 1949, to September, 1949; investigator in charge of plankton aboard the U.S. Fish and Wildlife vessel Albatross III, May and June, 1949.
Part-time Instructor, Duke University, September, 1949 to June, 1950.
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Publications:

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